363.34
A16MHV
1987-

MONTANA STATE LIBRARY
S 363.34 A16mhv 1987- c.1
Montana hazard/vulnarability analysis /p
3 0864 00059366 8

MONTANA STATE LIBRARY
1515 E. 6th AVE.
HELENA, MONTANA 59620

JUN 23 1988

APR 25 2003

# MONTANA

# HAZARD/VULNERABILITY ANALYSIS

STATE DOCUMENTS COLLECTION

JUN 23 1988

MONTANA STATE LIBRARY
1515 E. 6th AVE.

Prepared By

Montana Disaster and Emergency Services Division

Department of Military Affairs

1987

PLEASE RETURN

MAR 8 - 1989
MAR 21 1990
JUL 3 1991

Dear HVA User:

Enclosed are the first six sections of the revised Hazard/Vulnerability Analysis for the State of Montana. The completed document will identify and discuss potential major hazards which might impact the state, and the vulnerability to those hazards. The information provided will be helpful to emergency managers in setting priorities and goals for resource allocation and preparedness activities, thus improving disaster response capabilities.

This document has been designed to be used as a reference; sections and subsections have been outlined so that users may easily access specific information without reading text irrelevant to their needs. Each section will discuss a separate hazard. Within each section there are six subsections: Hazard Description, Historical Occurrence and Response, Prediction Potential for Recurrence, State Vulnerability to the Hazard, Mitigation, and Summary.

Additional sections scheduled for completion this year are Flood/Dam Failure and Tornado. Please put these under the appropriate tab as you receive them. Once completed, this document will be updated as new information becomes available. Any comments or suggestions are welcomed.

If you have any questions contact Shannon Heath at 444-6980.

Enclosure

RECORD OF CHANGES

| DATE OF CHANGE | PAGE(S) CHANGED | PERSON ENTERING CHANGE |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

## ACKNOWLEDGEMENTS

The Montana Disaster and Emergency Services Division would like to acknowledge the generous contributions of time and material by the following people:

**Montana State University, Department of Earth Sciences**

Steve Custer, Ph.D., Department Head
William Locke, Ph.D., Assistant Professor
Robert Taylor, Professor
Bradford R. Burton, Graduate Student
Michael Egan, Graduate Student
Donalee Esp, Graduate Student
Vern Heisler, Graduate Student
John Melesh, Graduate Student
Robbin L. Mills, Graduate Student
Douglas P. Richmond, Graduate Student
Hugh D. Safford, Graduate Student
Ginger Schmid, Graduate Student
Keith W. Smith, Graduate Student
Edward Spotts, Graduate Student

**Montana State University, Institute of Natural Resources**

Jim Heimbach, Ph.D., Associate Research Meteorologist

**University of Montana, Geology Department**

Arnold Silverman, Chairman
William P. Clement, Graduate Student
Kevin-Paul Craig Vang, Graduate Student

**Montana Department of Health and Environmental Sciences**

Daniel L. Fraser, Supervisor of Drinking Water Program
Kenneth L. Quickenden, Ph.D., R.S., Medical Entomologist and Sanitarian

**Montana Bureau of Mines and Geology, Earthquake Studies Office**

Michael C. Stickney, Director

**Great Falls Tribune**

T. J. Gilles, Agriculture Editor

TABLE OF CONTENTS

INTRODUCTION

NATURAL HAZARDS

- FLOOD/DAM FAILURE
- STORM
- TORNADO
- LANDSLIDE
- RESOURCE SHORTAGE
- AVALANCHE
- EARTHQUAKE
- FIRE
- VOLCANIC ERUPTION
- DROUGHT
- INSECT INFESTATION
- VECTOR-BORNE DISEASES

MAN-CAUSED HAZARDS

- HOSTILE ATTACK
- CIVIL DISORDER
- FIRE/EXPLOSION
- WATER CONTAMINATION
- AIR POLLUTION
- TRANSPORTATION ACCIDENT
- EPIDEMIC
- HAZARDOUS MATERIAL ACCIDENT

SUMMARY

# INTRODUCTION

## STATE DESCRIPTION

Prior to an indepth analysis of the hazards which potentially impact the State of Montana, it would be beneficial to review the general character of the State and its people.

Montana is the fourth largest state in the nation, exceeded in size by Alaska, Texas and California (Taylor et al, 1974). The state's east-west dimension averages 500 miles while the distance north to south averages 275 miles. Montana covers 147,138 square miles (94,168,000 acres), approximately 1,600 square miles (900,000 acres) of which is surface water. The State of Montana may be divided into three regions: The plains of eastern Montana cut by the Missouri, Yellowstone, Powder and Tongue Rivers, the foothill-interrupted plains in the center of the state, and the mountainous regions of the west (Van West, 1986).

The physical characteristics of the state contribute to its diverse climate. Other factors which determine the state's climate include altitude, the inland position of the state on the continent, and the movement of air masses and storms from various locations. Summer weather patterns cause a flow of unstable air into the state, resulting in several types of severe storms. The most troublesome of these storms are high-intensity rains and hail storms which cause crop and property damage. East of the divide, intense wind storms can occur several times a year. Tornadoes also occur infrequently in the eastern third of the state. Occasionally during the winter, a cold, dry air mass may build up which dominates eastern Montana and sometimes the entire state. Blizzards,

strong winds, blowing snow, and poor visibility may occur in conjunction with the onset of a cold wave.

Montana precipitation ranges from just over six inches in the southcentral part of the state to nearly 120 inches in the northwest. More than one-half of the state receives less than or equal to 14 inches of annual precipitation. Except for the western mountainous regions, Montana is a dry state, and as such, precipitation tends to be highly variable. Dry periods or wet periods lasting for a number of months and, at times, for several years are not uncommon in this state (Taylor et al, 1974).

Montana temperatures also vary widely; maximum temperatures exceeding 100 degrees have occurred at most recording stations in the state, and temperatures ranging well below zero occur almost every winter. The greatest temperature extremes occur east of the divide.

Water is an important resource in Montana; it plays an essential role in agriculture, industry, power production, the home and recreation. Since most surface water in the state originates as precipitation, Montana need not rely primarily upon inflow from other areas. Seasonal and annual dependability of streamflow is largely determined by runoff. Nearly half the state discharges less than one inch per year, however, mountainous areas along the Continental Divide discharge a high amount of runoff. The snowpack begins to melt in April and usually reaches a peak in late May or early June. Snow and channel ice which accumulate in eastern plains streams normally melt in late March or early April and may produce the peak flow of the year.

Montana contains over 1,500 natural lakes, located primarily in the mountainous areas of western and southcentral Montana. There are 67

reservoirs in the state, each of which have a total capacity of 5,000 acre-feet or more. Most of these reservoirs were constructed as single purpose projects for either stock-water storage or irrigation. Their value has increased over the years through being used for incidental flood control, fish and wildlife, and recreational benefits.

The quality of Montana's surface waters is generally rated from good to excellent. Principal exceptions include local bacterial contamination below municipal discharges, chemical and toxicity problems below mining and petroleum operations, and suspended sediment from periods of high stream runoff, geologic erosion, and improper land use activities.

Surface water serves primarily people who live in the cities and larger towns, while smaller towns rely almost exclusively on ground water for domestic consumption. Ground water in western Montana is of higher quality than that found in eastern Montana (DNRC, 1976).

The geography of the state is reflected in some population settlement patterns as shown in Figure 1. Areas of low density settlement usually represent regions of severe limitations imposed by terrain or moisture availability. Slightly more than 50 percent of the state's population reside in seven western counties: Yellowstone, Cascade, Missoula, Silver Bow, Flathead, Lewis and Clark and Gallatin (Taylor et al, 1974).

The population of an area directly affects its degree of vulnerability to any hazard (an acetate overlay of Figure 1 has been included at the back of this document for the purpose of combining it with appropriate maps in

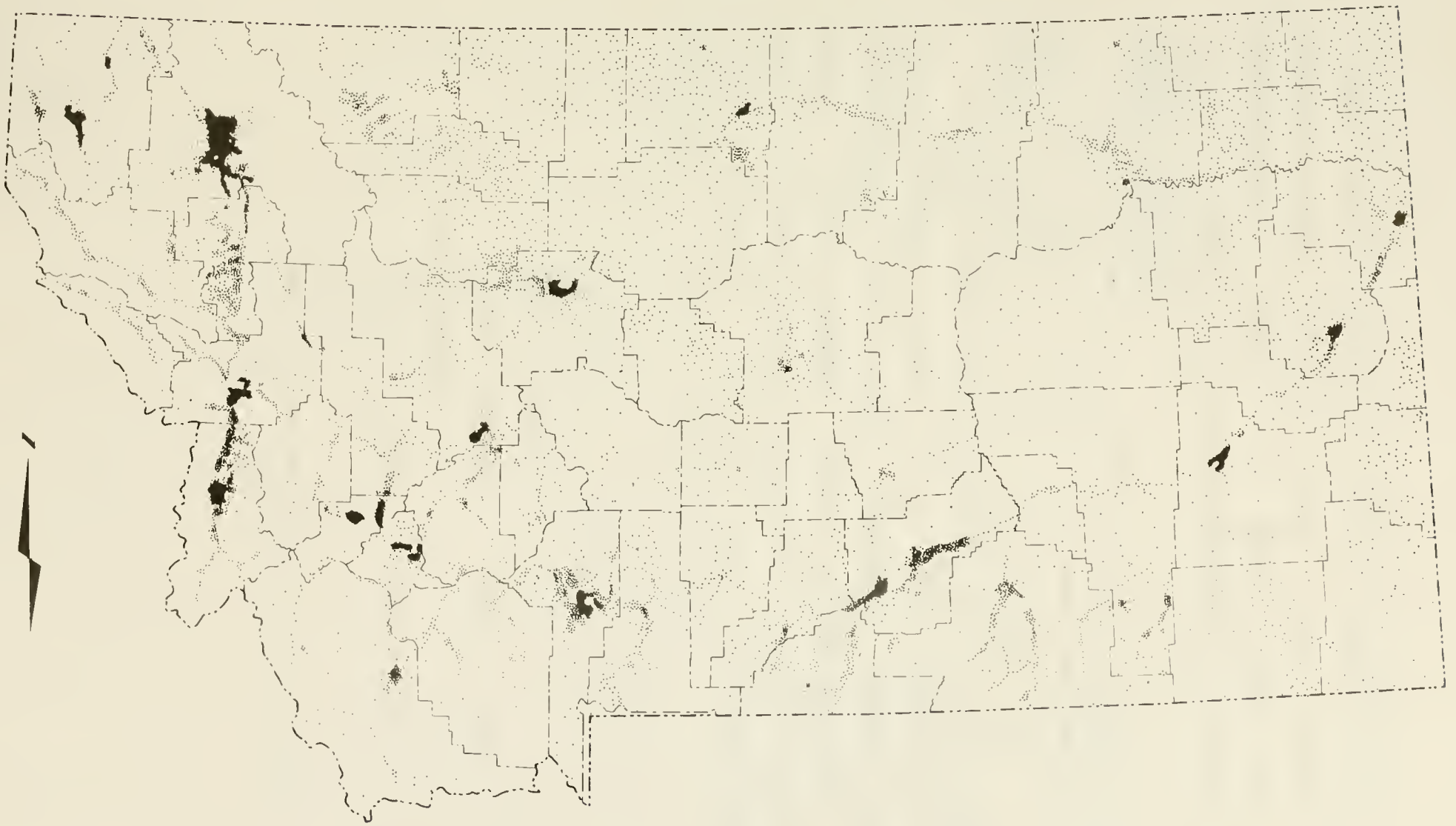


Figure 1. Population settlement patterns in Montana—1970.

One dot (.) represents 25 dispersed inhabitants.

Sources: U.S. Census, 1970
Department of Earth Sciences, Montana State University

the development of vulnerability profiles for specific hazards). Densely populated areas which coincide with high risk hazard locations would be considered highly vulnerable to the hazards involved while the same locations if sparsely populated would be considered less vulnerable.

## PURPOSE OF THE ANALYSIS

Emergency management has evolved from the single focus civil defense concern of the 1950's and 1960's to the present comprehensive, all-hazards approach by government at the local, state and federal levels.

In 1983 the Federal Emergency Management Agency (FEMA) implemented an Integrated Emergency Management System (IEMS) which emphasizes the all-hazards approach in the mitigation, preparedness, response, and recovery phases of emergency management. Effective emergency management, therefore, requires the identification and analysis of all hazards which potentially affect a jurisdiction. The first step in the IEMS process is the preparation of a hazard and vulnerability analysis.

The purpose of the analysis which follows is fourfold:

1. To communicate the importance and uses of a hazard and vulnerability analysis;
2. To increase awareness of potential hazards affecting the State of Montana;
3. To increase awareness of state vulnerability to those hazards; and
4. To communicate the importance of hazard mitigation.

Three objectives have been identified to fulfill the above-stated purpose:

1. Identify and analyze potential natural and man-caused hazards affecting Montana.
2. Assess state vulnerability to those hazards.
3. Suggest mitigation strategies.

## ANALYSIS OVERVIEW

During the ten-year period from 1975 to 1985 the governor of Montana declared 36 state disasters which resulted in the expenditure of thousands dollars for damage repair.

This document will identify and discuss potential major hazards which might impact the state, and the existing degree of vulnerability to those hazards. The information provided by this analysis will enable emergency management personnel to set priorities and goals for resource allocation and preparedness activities which will in turn enhance the capability to respond in the event of a disaster.

This report is the result of a comprehensive study of the types of disasters which have occurred in Montana as well as potential hazards which threaten the state. The information presented was drawn from literature review, studies conducted by Montana State University and University of Montana students and professors, communication with Montana State government personnel from various departments, and contacts with numerous private organizations.

The report format consists of a section covering each of the following hazards:

**Natural Hazards**

Flood/Dam Failure
Storm (blizzard, hail, wind)
Tornado
Landslide
Resource Shortage
Avalanche
Earthquake
Fire
Volcanic Eruption
Drought
Insect Infestation
Vector-Borne Diseases

**Man-Caused Hazards**

Hostile Attack
- Nuclear
- Chemical
- Terrorist

Civil Disorder
Fire/Explosion
Water Contamination
Air Pollution
Transportation Accident
- Air
- Rail
- Motor Vehicle

Epidemic
Hazardous Material Accident

Within each section there are six subsections: Hazard Description, Historical Occurrence and Response, Prediction Potential for Recurrence, State Vulnerability to the Hazard, Mitigation and Summary. A final section will summarize the discussion. Subsections have been delineated so that users may easily access specific information without reading text irrelevant to their needs. References used in researching each hazard will be listed in the respective section.

## REFERENCES

Michigan Department of State Police, 1985, Michigan hazard analysis: Emergency Management Division, Lansing, MI, 58 pp.

Montana Department of Natural Resources and Conservation, 1976, The framework report - A comprehensive water and related land resource plan for the State of Montana: Water Resources Division, V.1, 101 pp.

Taylor, R.L., Edie, M.J., and Gritzner, C.F., 1974, Montana in maps: Montana State University, Bozeman, MT, 75 pp.

Van West, C., 1986, A traveler's companion to Montana history: A Montana Historical Society Guide, Helena, MT, 239 pp.

# FLOOD/DAM FAILURE

## DESCRIPTION

Floods constitute one of the most destructive natural hazards facing Montana. Flooding occurs when abnormally high streamflow overtops the natural or artificial banks of a water course (Hays, 1981).

Flood damage results primarily from the continued encroachment by man on floodplains (National Science Foundation, 1980). A floodplain is described as the combined area of the floodway and floodway fringe (see Figure 1). The term floodway refers to the central portion of the floodplain that contains the stream and enough of the surrounding land to enable flood waters to pass without increasing flood depths upstream (FEMA, 1986).

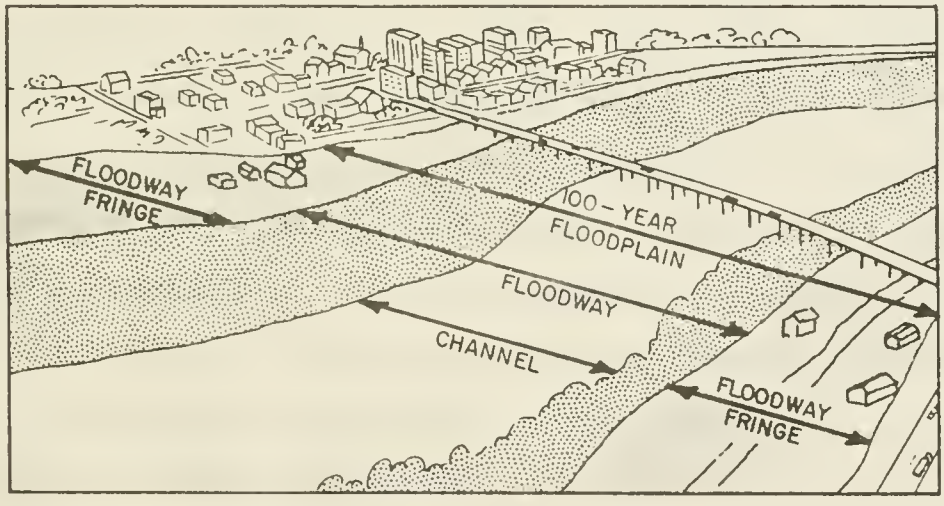



**FIGURE 1:** A floodplain is described as the combined area of the floodway and the floodway fringe (MDNRC, 1987)

The most severe damage to persons and/or property occurs in this zone. The area beyond the floodway in which water does not actively flow or flows at a minimal rate during a flood, or where standing water accumulates is

considered the floodway fringe. Although the force of flood waters in the floodway fringe is likely to be less destructive, property damage may be more extensive because most floodplain development is located in this fringe area (Jim E. Richard Consulting Services et al, 1986).

A flood's magnitude is expressed as the frequency with which a flood of a given volume is expected to occur. The 100 year flood is used as the standard for defining the flood hazard for development. A flood of this magnitude would be expected to occur once every 100 years or have a one percent chance of occurring during any year. The Federal Emergency Management Agency (FEMA) and the Montana Department of Natural Resources and Conservation delineate the boundaries of the 100 year floodplain on maps to provide assistance in planning and managing associated development (Jim E. Richard Consulting Services et al, 1986).

There are three principal types of floods which may affect Montana: riverine floods, flash floods, and dam break floods. Riverine floods result from precipitation over large areas and/or from snowmelt. This type of flood occurs in river systems whose tributaries may drain large geographic areas and include many independent river basins. The duration of riverine floods may vary from a few hours to many days. Factors which directly affect the amount of flood runoff include precipitation amount, intensity and distribution, the amount of soil moisture, seasonal variation in vegetation, snow depth and water-resistance of the surface due to urbanization.

The term "flash floods" describes local floods of great volume and short duration. In contrast to riverine flooding, this type of flood usually results from a torrential rain on a relatively small drainage area.

Precipitation of this sort usually occurs in the summer. The sudden break-up of an ice jam or the failure of a dam may also result in flash flooding. Flash floods are a potential threat to life and property in areas characterized by steep terrain, high surface runoff rates, and narrow canyon streams and/or subject to severe thunderstorms.

Flooding may also result from the failure of a dam. Dam break floods are usually associated with intense rainfall or prolonged flood conditions. The greatest threat to people and property is normally in areas immediately below the dam since flood discharges decrease as the flood wave moves downstream. Dam failure may be caused by faulty design, construction and operational inadequacies, or a flood event larger than the design flood (Hays, 1981). The degree and extent of damage depend on the size of the dam and the circumstances of failure. A small dam retaining water in a stock pond may break resulting in little more damage than the loss of the structure itself. In contrast, a dam break could result in the loss of irrigation water for a season causing extreme financial hardship to many farmers. An even larger dam failure might bring about considerable loss of property, destruction of cropland, roads and utilities and even loss of life. More far-reaching consequences can include loss of income, disruption of services and environmental devastation (LaFrance, 1984).

## HISTORICAL OCCURRENCE AND RESPONSE

All three types of floods just described (riverine floods, flash floods and dam failure floods) have occurred in Montana's main river basins (see Figure 2). The counties that received Presidential disaster declarations from 1964 to 1986 due to flooding are shown in Figure 3. The following

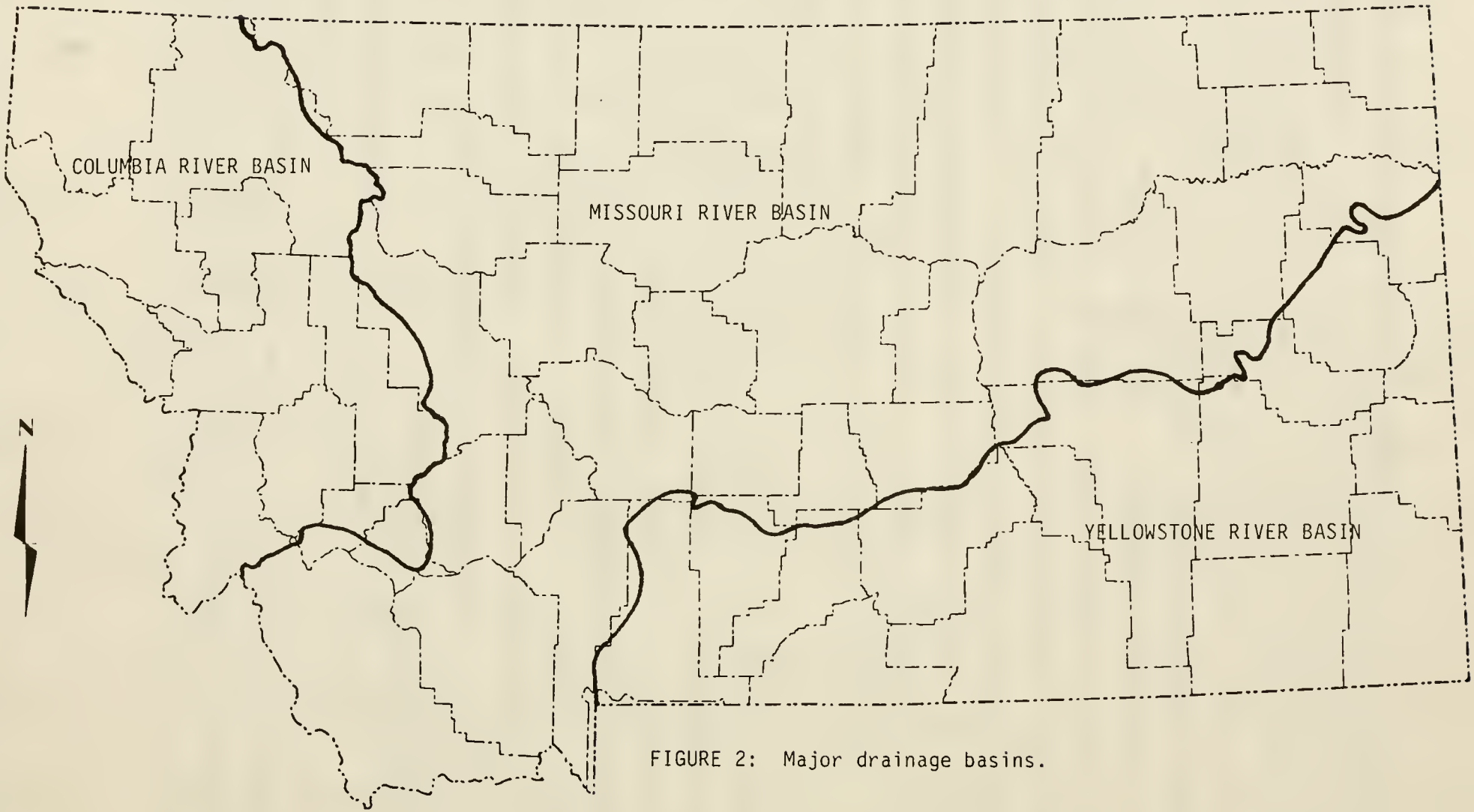



FIGURE 2: Major drainage basins.

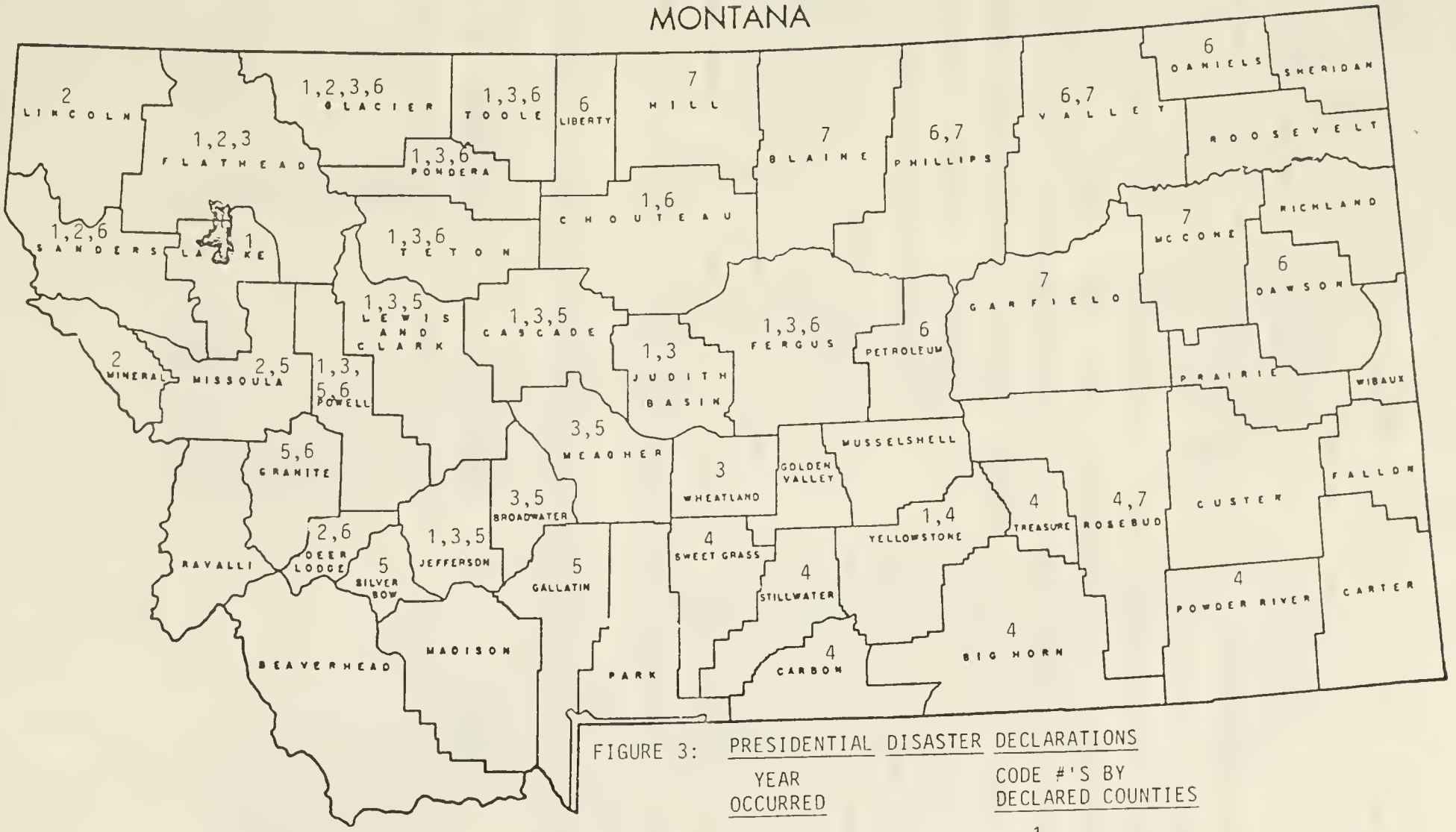



FIGURE 3: PRESIDENTIAL DISASTER DECLARATIONS

| YEAR OCCURRED | CODE #'S BY DECLARED COUNTIES |
|---|---|
| 1964 | 1 |
| 1974 | 2 |
| 1975 | 3 |
| 1978 | 4 |
| 1981 | 5 |
| 1986 | 6 |

No. 1052 -- County Outline Map
STATE PUBLISHING COMPANY
Helena

discussion will give historical examples of each flood type. The reader should realize that there is some overlap between the flood types.

The Flathead River in the Columbia River Basin has been subject to numerous significant flooding events over the years (see Table 1). A June flood in Missoula County in 1908 involved nearly every major stream and river. This event was the result of unseasonably warm temperatures and thirty-three (33) consecutive days of rain (Henry, 1987). In June 1964, approximately fifteen (15) inches of rain accumulated over a thirty (30) hour period in the upper Flathead drainage. The resulting flood damaged more than 350 houses in the vicinity of Kalispell. The Corps of Engineers estimated that the damages in the Flathead Basin totalled $25 million. In January 1974, the counties of Lincoln, Sanders, Flathead, Glacier, Mineral, Missoula and Deer Lodge were hit by flood waters which caused approximately $16 million worth of damage to Forest Service roads, bridges and facilities, private property, etc. These same counties suffered flood related losses again in June 1975, totaling nearly $35 million (Montana Civil Defense Division, 1976).

**TABLE 1:** History of flooding in the Columbia River Basin (see bottom Table 3 for sources).

| SOURCE OF FLOODING | URBAN AREAS IMPACTED | YEARS OF FLOOD EVENTS |
|---|---|---|
| Middle Fork Flathead R. | W. Glacier, Nyack | 1964, 1975 |
| Kootenai R. | Libby, Troy | 1916, 1948, 1974 |
| Stillwater R. | | 1948 |
| Belly R. | St. Mary | 1964 |
| Big Cherry Crk. | Libby | 1974 |
| Flower Crk. | Libby | 1974 |
| Libby Crk. | Libby | 1974 |
| Parmenter Crk. | Libby | 1974 |
| Flathead R. | Flathead Valley, Evergreen, Columbia Falls, Kalispell | 1894, 1928, 1933, 1948, 1964, 1975 |

TABLE 1 (Cont'd)

| SOURCE OF FLOODING | URBAN AREAS IMPACTED | YEARS OF FLOOD EVENTS |
|---|---|---|
| Clark Fork R. | Thompson Falls, Drummond, Clinton, Noxon, Yaak, Missoula, Garrison | 1908, 1948, 1964, 1974, 1975, 1981, 1986 |
| Jocko R. | | 1964 |
| Bear Crk. | | 1964, 1975 |
| Ashley Crk. | | 1948 |
| Rattlesnake Crk. | | 1908, 1948, 1974 |
| Blackfoot R. | Lincoln, Missoula | 1908, 1927, 1964, 1974, 1975 |
| Pattee Crk. | Missoula (So. Hills) | 1962, 1964, 1967, 1976, 1980 |
| Camp Crk. | Philipsburg | 1974 |
| Frost Crk. | Philipsburg | 1974 |
| Edwards Gulch | Drummond | 1974 |
| Flint Crk. | | 1943 |
| Rock Crk. | Clinton | 1927, 1972, 1975 |
| Little Blackfoot R. | Elliston, Avon, Garrison | 1981 |
| Cottonwood Crk. | Deer Lodge | 1908, 1916, 1917, 1928, 1948, 1964, 1975, 1981, 1986 |
| Warm Springs Crk. | Anaconda | 1948, 1958, 1965, 1967, 1974, 1986 |
| Bitterroot R. | Bell Crossing, Darby, Florence, Hamilton, Corvallis | 1899, 1908, 1947, 1948, 1972, 1974 |

The most damaging flood in the Missouri River Basin occurred in June 1964 (see Table 2). The principal rivers involved were the Dearborn, Sun, Teton and Marias. The event was initiated by eight to ten inches of rain over three days on a deeper than average snowpack. All counties situated along the Continental Divide were affected to some degree, however, the greatest damage was received by the City of Great Falls. This disaster resulted in the loss of thirty (30) lives and an estimated $55 million in damages. The Corps of Engineers recently completed a $12 million dollar flood control levee along the north bank of the Sun River near Great Falls, which protects over 500 homes and businesses (Henry, 1987).

The combination of snowmelt and spring rains with frequent ice jams causes flooding on the Beaverhead River near Dillon. During the most recent flood, 1984, crews successfully prevented major damage by channeling floodwaters through town on streets lined with sandbags and straw. The Clark Canyon Dam above Dillon and emergency dikes built on the river near town reduced potential damages (Henry, 1987).

**TABLE 2:** History of flooding in the Missouri River Basin.

| SOURCE OF FLOODING | URBAN AREAS IMPACTED | YEARS OF FLOOD EVENTS |
|---|---|---|
| Missouri R. (Mainstem) | Great Falls to Ft. Benton | 1953, 1964, 1981, 1986 |
| Dearborn R. | Great Falls | 1894, 1899, 1908, 1916, 1927, 1936, 1948, 1953, 1958, 1964, 1965, 1966, 1969, 1975, 1981, 1986 |
| Sun R. | Great Falls, Augusta, Simms | 1953, 1964, 1975 |
| Teton R. | Choteau, Ft. Benton | 1908, 1916, 1948, 1953, 1964, 1975, 1986 |
| Elk Crk. | Augusta | 1964, 1975 |
| Spring Crk. | Choteau | 1964, 1975, 1986 |
| Muddy Crk. | Choteau, Vaughn | 1964, 1975, 1986 |
| Belt Crk. | Belt, Neihart | 1908, 1953, 1981 |
| Highwood Crk. | Highwood | 1953 |
| Blackfoot R. | Lincoln | 1964, 1975 |
| Marias R. | Shelby, Kevin | 1953, 1964, 1975 |
| Birch Crk. | Dupuyer | 1964 |
| Midvale Crk. | East Glacier | 1964 |
| Willow Crk. | Browning | 1964 |
| Dupuyer Crk. | | 1964, 1975, 1986 |
| Cut Bank Crk. | | 1964, 1974, 1975, 1986 |
| St. Mary R. | St. Mary | 1964 |
| Belly R. | Glacier Nat'l Park | 1964 |
| Waterton R. | Glacier Nat'l Park | 1964 |
| Milk R. | Glacier, Havre, Nashua, Glasgow, Dodson, Chinook, Harlem, Malta, Saco | 1880, 1888, 1899, 1906, 1907, 1912, 1917, 1922, 1925, 1927, 1939, 1943, 1952, 1953, 1964, 1978, 1979, 1986 |

TABLE 2 (Cont'd)

| SOURCE OF FLOODING | URBAN AREAS IMPACTED | YEARS OF FLOOD EVENTS |
|---|---|---|
| Big Spring Crk. | Lewistown | 1920, 1947, 1953, 1964, 1975, 1986 |
| S. Fork McDonald Crk. | Grass Range | 1938, 1962, 1964, 1965, 1975, 1979 |
| Big Casino Crk. | Denton | 1978, 1979 |
| Tenmile Crk. | Helena Valley, Helena | 1908, 1964, 1975, 1981 |
| Sevenmile Crk. | Helena Valley, Helena | 1964 |
| Prickly Pear Crk. | Helena Valley, East Helena | 1908, 1964, 1975, 1981 |
| Wolf Crk. | Wolf Creek | 1964 |
| Boulder R. | Boulder | 1964, 1975, 1981 |
| Smith R. | | 1981 |
| Basin Crk. | Basin | 1981 |
| E. Gallatin R. | Bozeman | 1948, 1958, 1969, 1970, 1971, 1981 |
| Rocky Crk. | Bozeman | 1981 |
| Bridger Crk. | Bozeman | 1970, 1981 |
| Cataract Crk. | Bozeman | 1981 |
| Hyalite Crk. | Bozeman | 1981 |
| Bear Canyon Crk. | Bozeman | 1981 |
| Bozeman Crk. | Bozeman | 1893, 1937, 1947, 1948, 1958, 1960, 1969, 1970, 1974, 1975, 1977 |
| Mathew-Bird Crk. | Bozeman | 1960 |
| W. Gallatin R. | | 1952, 1959, 1963, 1970, 1971, 1974, 1975 |
| Jefferson R. | Three Forks Area | 1899, 1908, 1927, 1948 |
| Madison R. | | Nearly every year before 1920, 1949, 1972, 1975, 1978 |
| Silver Crk. | | 1964, 1975 |
| Blacktail Deer Crk. | Dillon | 1964, 1984 |
| Beaverhead R. | Dillon | 1937, 1949, 1951, 1964, 1974, 1979, 1984 |

Significant floods have occurred on the Milk River and its tributaries primarily as a result of rapid snowmelt over frozen soil. Heavy rains caused the greatest flood on record for this river in April 1952; damages between Havre and the river's mouth below Nashua were in the millions of

dollars. Levees offer limited protection to the communities of Havre, Chinook, Malta, Saco, Glasgow, and Nashua, however, several are in need of repair (Henry, 1987).

The Yellowstone River system is one of the remaining large rivers in this country which does not have a major flood control dam, with the exception of the Yellowtail Dam on the Big Horn River. Large floods have affected the Glendive area near the end of the Yellowstone River typically as a result of ice jams (see Table 3). Flooding in 1899 took four lives and destroyed a new bridge. The Corps of Engineers built a levee in 1959 which protects a portion of the town. Miles City, located at the junction of the Tongue and Yellowstone Rivers is one of the more floodprone towns in the state. Limited protection of the city is afforded by levees (Henry, 1987).

Flash Floods

Flash flooding is common in some areas of the state during the summer storm season. The best examples of this type of flooding have occurred in the Billings area. Flooding of the tributaries of the Yellowstone has resulted from intense summer thunderstorms, typically short in duration, which produce high peak flows. Major flooding of this type occurred in 1923 and 1937 (Henry, 1987). Flash flooding is also common along drainages in Lincoln, Sanders, Flathead, Glacier, Mineral, Missoula and Deer Lodge Counties during the summer storm season (Montana Civil Defense Division, 1976).

**TABLE 3:** History of flooding in the Yellowstone river Basin.

| SOURCE OF FLOODING | URBAN AREAS IMPACTED | YEARS OF FLOOD EVENTS |
|---|---|---|
| Yellowstone R. | Livingston, Billings, Miles City | 1894, 1918, 1928, 1937, 1943, 1944, 1967, 1971, 1974, 1975, 1978 |

TABLE 3 (Cont'd)

| SOURCE OF FLOODING | URBAN AREAS IMPACTED | YEARS OF FLOOD EVENTS |
|---|---|---|
| Yellowstone R. | Glendive | 1899, 1916, 1920, 1936, 1943, 1969, 1986 |
| Tongue R. | Miles City | 1882, 1887, 1888, 1892, 1899, 1902, 1909, 1912, 1918, 1923, 1928, 1929, 1944, 1949, 1969, 1971, 1974, 1986 |
| Lone Tree Crk. | Sidney | 1951, 1972 |
| Lower Deer Crk. | | 1918, 1967 |
| Powder R. | Broadus | 1978 |
| Little Bighorn R. | Hardin, Crow Agency | 1978 |
| Bighorn R. | St. Xavier | 1978 |
| Pryor Crk. | Pryor, Billings | 1978 |
| Italian Ditch | Laurel | 1978 |
| Stillwater R. | Countywide | 1967, 1974, 1975, 1978 |
| Rock Crk. | Red Lodge | 1952, 1957, 1967, 1975, 1978 |
| Boulder R. | Big Timber | 1956, 1974, 1975 |

Sources for Tables 1, 2 and 3: Boner and Stermitz 1981-1985; FEMA, 1979, 1981-1985; Henry, 1987; Johnson and Omang, 1974; Johnson and Omang, 1976; Paulsen, 1949; Wells, 1955; Wells, 1957.

## Dam Failure Floods

Dam failure floods in Montana have primarily been associated with riverine and flash flooding. Never-the-less the potential for a major flood occurring solely as a result of dam failure is a real possibility. The loss of thirty (30) lives during the 1964 flood in the Missouri River Basin was due primarily to the sudden failure of Swift Reservoir on Birch Creek and Two Medicine Dam on Two Medicine Creek. There was no time to warn residents in the creek valley below. During the 1952 flooding of the Milk River, Frenchman Dam on Frenchman Creek failed. This caused the highest peak ever

recorded on the Milk River below its confluence with Frenchman Creek (Henry, 1987).

In 1927, Pattengail Creek Dam in Beaverhead County failed causing four known deaths and near complete destruction of the towns of Dewey and Wise River. More recently, June 20, 1984, Browns Lake Dam, also located in Beaverhead County, was overtopped resulting in washed out roads and bridges downstream. Estimated property damage amounted to $100,000 (LaFrance, 1984).

## PREDICTION POTENTIAL FOR RECURRENCE

History has shown that floods are natural and recurrent events. On the basis of present knowledge, the size, time and location of flooding is difficult to predict in advance (Hays, 1981). When discussing flood recurrence potential both long-term and short-term predictions must be taken into consideration. The following information is necessary in order to make long-term predictions of potential flooding in a jurisdiction:

1) Potential sources of flooding which affect the jurisdiction. All streams, rivers, canals and reservoirs within the jurisdiction have the potential to contribute to a flood.

2) Potential causes of flooding from each source. Rainfall, snowmelt and dam failure are the primary factors in initiating flooding.

3) Likely characteristics of flooding from each source. These include magnitude, speed of onset, season of occurrence and depth (FEMA, 1983). As discussed earlier, a flood's magnitude is expressed as the frequency with which a flood of a given volume is expected to occur (Jim E. Richard Consulting Services et al, 1986). The probability of occurrence of floods of various magnitudes at a site may be determined by statistical

analysis of annual peak discharges for all years of record at that site. Annual peak discharge is the highest rate of flow in a stream in a twelve month period. A common practice is to refer to a peak discharge of a given magnitude in terms of its return period. For example, a peak discharge that has a two-percent chance of occurring during any year would be expected to occur once in 50 years. The speed of onset is the amount of time which passes between flood warning and impact on a community. This would depend on the type of floods a jurisdiction might experience. A community situated below a dam or in an area which is subject to flash flooding can expect a rapid speed of onset. History should indicate the seasonality and depth of floods characteristic of an area (FEMA, 1983). Flooding may take place in all seasons: fall/winter floods due to rainfall and temperature patterns; spring floods from snowmelt, ice jams or seasonal rainfalls; summer flooding due to thunderstorms which affect small areas (Hays, 1981). The heaviest precipitation in Montana occurs between April and September. The mountain snowpack begins to melt in April and usually reaches a peak in late May or early June. Runoff is essentially completed in July. Annual peak discharges normally occur in late March or early April. Later increases in streamflow are dependent upon rain of sufficient intensity and duration to cause surface runoff (MDNRC, 1976).

The information listed in 1, 2 and 3 above is often available from various government agencies (see listing under Mitigation, this section). Emergency managers equipped with the above information would be far more knowledgeable about flooding potential in their jurisdictions. Possessing the information necessary to make long-term flood predictions enables an emergency manager to institute effective flood mitigation techniques.

Short-term flood prediction potential does not allow much time for enacting mitigation measures, however, it may be critical in saving lives and reducing property damage. Chief sources of information for predicting an impending flood include:

1) Rainfall forecasts, radar information, satellite imagery and comprehensive data available from the National Weather Service.

2) Upstream rainfall and streamflow measurements, collected by observers or automated equipment.

3) Reports of upstream flows and flooding from other communities, state police and other sources (FEMA, 1983).

Much of the information necessary to assess an area's potential for flooding will also give some indication of area vulnerability to flooding.

## STATE VULNERABILITY TO FLOODING

Flooding becomes a hazard when people compete with nature for the use of floodplains. If floodplain areas were left in their natural state, flooding would not cause major damage. Urban, industrial and other surface development in natural floodplain areas of Montana has increased the vulnerability to serious flooding. The extent of artificial surface area created by development prevents rainfall from soaking into the ground and increases the rate of runoff (National Science Foundation, 1980).

As stated previously, Montana is vulnerable to riverine and flash flooding, and dam failure floods.

### Riverine and Flash Flooding

Since the major differences between riverine and flash flooding relate to speed and season of onset rather than impacted areas, these two types of flooding will be addressed here as one.

It is difficult to assess area specific vulnerability to flooding at the scale of this analysis. Any area, through which a water course flows, may be vulnerable to flooding. Those areas which have been subject to past flooding are the most likely to be vulnerable in the future. The Historical Occurrence and Response subsection noted some examples of past flooding including those that caused damage of such proportions as to warrant Presidential disaster declarations. These areas will undoubtedly be subject to flooding again. The potential impact is compounded as development continues to encroach upon floodplains.

Based on the above knowledge the logical items of information to consider in assessing the State's vulnerability to flooding are location of water courses, historical flooding events, and population distribution. Figure 4 shows the major water features in Montana. The combination of this map with the population distribution overlay (found in the back pocket of this binder) reveals areas where population settlement and floodplains probably overlap. This overlap represents a potential hazard. If these areas have experienced flooding in the past their vulnerability to future flooding should be considered high. Continued development will naturally increase that vulnerability.

Local emergency managers can refine this information by studying the situation more closely for their jurisdiction. Maps that outline floodplains and/or flood hazard areas in most jurisdictions are available from the Flood Plain Management Section of the Montana Department of Natural Resources and Conservation, the Federal Emergency Management Agency, the Soil Conservation Service and the U.S. Geological Survey (FEMA, 1983). It

Figure 4. Major water features in Montana

Sources: Earth Sciences Department, Montana State University
Montana Department of Natural Resources and Conservation

is critical that the emergency manager determine site-specific vulnerability in order to effectively implement mitigation strategies.

Dam Failure Flooding

There are a number of concrete and earth fill dams throughout the state designed for power and/or irrigation that also present potential flood problems (MT Civil Defense Division, 1976). Some of these dams are considered unsafe for various reasons. Many are considered unsafe due to improper operation and poor maintenance (LaFrance, 1984). Some were not designed to withstand even half the flow expected to occur during severe flooding could not pass without overtopping the dam. Other improper design and construction methods such as adding a few feet of earth to the top of an existing dam to increase storage capacity could lead to greater risk and magnitude of failure.

Vulnerability to dam failure flooding is compounded by the fact that the false sense of security created by an upstream dam encourages settlement in the flood hazard area below the dam (National Science Foundation, 1980). Extreme events could exceed the flood storage capacity of even large reservoirs. At such times, the excess water passed over the spillway (the primary purpose of which is to protect the dam) may cause damages downstream which could approach those that would have occurred had the dam not been built. However, the failure of a dam could produce flood rates and damages in excess of that which would have resulted if the dam had not been built (Committee on Safety Criteria for Dams et al, 1985).

In 1981, the United States Army Corps of Engineers completed inspection of non-federal dams in Montana. Generally, the Corps inspected dams which were at least twenty-five (25) feet high or impounded at least fifty (50)

acre-feet of water and were located upstream from populated areas or areas where dam failure could cause serious property damage. Thirty-six (36) dams received unsafe classifications and deficiencies were found in all other dams inspected (U.S. Army Corps of Engineers, 1981). Since that time, three of the thirty-six (36) have been breached and one has been rehabilitated (McDonald, 1987). Table 4, lists those dams classified as unsafe while Figure 5, graphically locates them. The most common problem identified was an inability to safely handle flood flows (U.S. Army Corps of Engineers, 1981).

**TABLE 4:** Non-federal dams classified as unsafe by U.S. Army Corps of Engineers:

| Name | County | River | Date of * Report |
|---|---|---|---|
| 1. Lima | Beaverhead | Red Rock River | 07-25-80 |
| 2. Tongue River Dam | Big Horn | Tongue River | 12-15-80 |
| 3. Storm Lake Dam | Deer Lodge | Storm Lake Creek | 06-25-81 |
| 4. Lower Baker Dam | Fallon | Sandstone Creek | 06-27-79 |
| 5. South Sandstone Crk. Dam | Fallon | South Sandstone Creek | 04-30-81 |
| 6. Big Casino Creek Dam | Fergus | Big Casino Creek | 03-27-81 |
| 7. East Fork Dam | Fergus | East Fork Big Spring | 03-27-81 |
| 8. Hanson Creel Dam | Fergus | Hanson Creek | 03-27-81 |
| 9. Pike Creek Dam | Fergus | Pike Creek | 03-27-81 |
| 10. Middle Creek Dam | Gallatin | Hyalite Creek | 07-11-80 |
| 11. Lower Willow Creek Dam | Granite | Lower Willow Creek | 02-25-81 |
| 12. Beaver Creek Reservoir Dam | Hill | Beaver Creek | 03-26-81 |
| 13. Delmoe Lake Dam | Jefferson | Big Pipestone Creek | 05-15-80 |
| 14. Big Sky Dam | Madison | Middle Fork, West Fork, Gallatin River | 04-09-81 |
| 15. Cataract Creek Dam | Madison | Cataract Creek | 07-22-80 |
| 16. Lower Branham Dam | Madison | N. Fork Mill Creek | 02-27-81 |
| 17. Ruby Dam | Madison | Ruby River | 08-02-80 |
| 18. Willow Creek Dam | Madison | Willow Creek | 08-13-80 |
| 19. Bair Dam | Meagher | N. Fork Musselshell River | 03-11-81 |
| 20. Hanson Reservoir Dam | Meagher | Woods Gulch Creek | 03-25-81 |
| 21. Newlan Creek Dam | Meagher | Newlan Creek | 05-04-81 |
| 22. N. Fork of Smith River Dam | Meagher | North Lake Smith River | 05-08-81 |

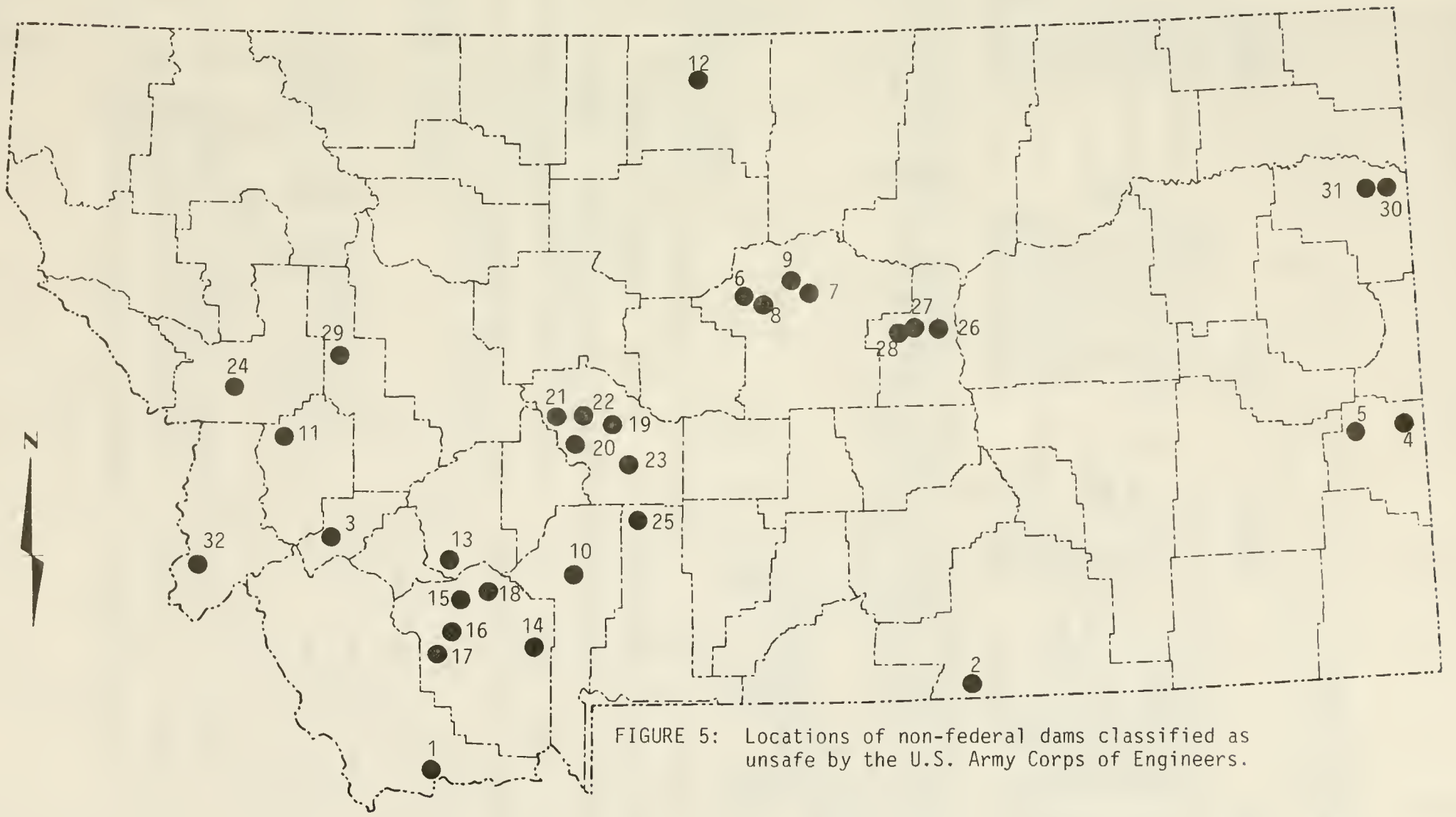



FIGURE 5: Locations of non-federal dams classified as unsafe by the U.S. Army Corps of Engineers.

TABLE 4 (Cont'd)

| Name | County | River | Date of * Report |
|---|---|---|---|
| 23. Voldseth West Dam | Meagher | Tr-Comb Creek | 10-31-80 |
| 24. Wallace Creek Dam | Missoula | Wallace Creek | 04-29-81 |
| 25. Cottonwood Dam | Park | Cottonwood Creek | 03-04-81 |
| 26. Petrolia | Petroleum | S. Fork Flatwillow Creek | 01-16-81 |
| 27. Yellow Water Dike | Petroleum | Yellow Water Creek | 10-22-80 |
| 28. Yellow Water Main | Petroleum | Yellow Water Creek | 10-22-80 |
| 29. Nevada Creek Dam | Powell | Nevada Creek | 01-29-81 |
| 30. Vaux No. 1 | Richland | Lone Tree Creek | 03-04-80 |
| 31. Vaux No. 2 | Richland | Lone Tree Creek | 03-04-80 |
| 32. Tin Cup Lake Dam | Ravalli | Tin Cup Creek | 09-09-81 |

* Personal communication with Glen McDonald, Project Rehabilitation Supervisor, DNRC, on March 19, 1987, confirmed that the dams listed here are still considered unsafe (i.e., sufficient repair has not taken place to date to remove them from the unsafe category).

## MITIGATION

Although floods are not subject to complete control by man, they do occur in areas which can be defined with a fair degree of accuracy. Theoretically then, it is possible to reduce potential damage through the selection and implementation of various mitigation techniques. Past mitigation has ranged from warnings and preventive measures before a flood (e.g., dams, levees, etc.), to costly relief and rehabilitation afterward (National Science Foundation, 1980). Current mitigation techniques are far more diverse and attempt, where possible, to avoid the problem rather than merely treat the symptoms of the problem.

Some flood hazard mitigation techniques apply to all three flood types previously reviewed. These techniques will be discussed first followed by mitigation strategies which apply directly to dam failure.

Flood hazard mitigation strategies are generally classified as either non-structural or structural. The distinction is not always clear. Non-structural measures generally attempt to modify susceptibility to flood

damage through such means as regulatory and administrative approaches, while structural techniques usually employ engineering approaches to contain floods (FEMA, 1983).

Non-structural Mitigation

Non-structural mitigation techniques may be considered either preventive or corrective (see Table 5). Preventive actions are those which are primarily directed toward vacant, undeveloped flood-plains and which may be taken any time during either the pre- or post- disaster period. Corrective actions are those which attempt to mitigate flood damages that occur as a result of unwise development of flood hazard areas (FEMA, 1981).

TABLE 5: Non-Structural Flood Hazard Mitigation Techniques.

| | Relative Length of Time for Implementation | | |
|---|---|---|---|
| | Short Term | Mid-Term | Long-Term |
| **Corrective Techniques** | | | |
| 1. Acquisition and Relocation | | X | X |
| 2. Floodproofing | X | | |
| 3. Structural Elevation | X | | |
| 4. Floodwalls and Levees | X | | |
| 5. National Flood Insurance Program (discussed only under preventive techniques) | X | X | |
| 6. Disaster Contingency Planning | | X | |
| 7. Flood Forecasting & Warning Systems | | | X |
| **Preventive Techniques** | | | |
| 1. Research | | | |
| 2. Information and Education | X | | |
| 3. National Flood Insurance Program | X | X | |
| 4. Comprehensive Community Planning | | | X |
| 5. Regulations to Control Floodplain Development | | | |
| a. Zoning ordinances | X | | |
| b. Subdivision regulations | X | | |
| c. Building permits and building codes | X | | |
| d. Soil erosion and sedimentation controls | X | | |
| e. Stormwater runoff controls | X | | |

TABLE 5 (Cont'd)

| | | | |
|---|---|---|---|
| 6. | Drainage and Flood Control Criteria | X | |
| 7. | Master Drainageway Planning | | X |
| 8. | Public Acquisition of Flood Prone Lands for Park, Recreation and Open Space Purposes | X | |
| 9. | Community Policy regarding provision of Public Facilities and Utilities in Floodplain Areas | X | |

Preventive Techniques

1. **Research.** Flood mitigation strategies must be designed to meet the particular needs of the area to be served. Emergency managers should gain a thorough understanding of the flood problem and area at risk in their jurisdictions. Pertinent, site-specific information is often available from local, state and federal agencies. Volunteer organizations also provide sources of assistance. Some examples include weather and flood forecasting agencies, water resources agencies, Red Cross, emergency services, local assessors, local planning agencies, etc. Table 6, lists potential sources of federal assistance.

2. **Information and Education.** Once the necessary technical information on flood hazard potential has been researched an information and education program must be developed. Awareness by the general public, government officials, community decision-makers, planners and floodplain occupants, of the value of hazard mitigation and the benefits of floodplain management is necessary in order to gain their support. Local officials should be encouraged to give the same attention and priority to drainage problems as to police and fire problems since flooding can take as many or more lives. The program should explain the nature of

floods, the relationship between unwise development and damage, hazard mitigation options and available assistance (National Science Foundation, 1980). Methods of disseminating information include informational maps and brochures mailed to floodplain occupants, marking of public structures and bridges with the 100-year or historical flood level, warning signs, public service announcements on radio and television, and educational articles in local newspapers (FEMA, 1981).

TABLE 6: Available Federal Assistance for Program Development (Key at end of Table) (FEMA, 1983).

| ELEMENT | FINANCIAL ASSISTANCE | PLANNING AND TECHNICAL ASSISTANCE | USEFUL INFORMATION |
|---|---|---|---|
| PROBLEM ANALYSIS | CDBG[4]<br>FEMA[3] | ES<br>FEMA<br>NWS[1]<br>PHS<br>RC<br>SCS[1]<br>USCE[1] | BR[1]<br>ES<br>FEMA[1]<br>NWS[1]<br>RC<br>SCS[1]<br>USCE[1]<br>USGS[1] |
| WARNING | CDBG[4]<br>FEMA[3]<br>NWS[1] | BR<br>NWS[1]<br>SCS<br>USCE[1] | BR<br>NWS[1]<br>SCS<br>USCE<br>USGS |
| EVACUATION AND RESCUE | CDBG[4]<br>FEMA[3] | BR<br>ES<br>FEMA<br>NWS<br>RC[1]<br>SCS[1]<br>USCE[1] | BR<br>ES<br>FEMA<br>NWS<br>PHS<br>RC[1]<br>SCS<br>USCE<br>USGS |
| DAMAGE REDUCTION | CDBG[4]<br>FEMA[3]<br>SCS[2] | BR<br>ES<br>PHS<br>SCS<br>USCE[1] | BR<br>ES<br>RC<br>SCS<br>USCE[1]<br>USGS |

TABLE 6 (Cont'd)

| ELEMENT | FINANCIAL ASSISTANCE | PLANNING AND TECHNICAL ASSISTANCE | USEFUL INFORMATION |
|---|---|---|---|
| RECOVERY | CDBG[4]<br>FEMA[3]<br>RC[1]<br>SCS[1] | BR<br>ES<br>FEMA[1]<br>PHS<br>RC[1]<br>SCS<br>USCE[1] | BR<br>ES<br>FEMA[1]<br>PHS[1]<br>RC[1]<br>SCS<br>USCE |
| PLAN IMPLEMENTATION | CDBG[4]<br>FEMA[3] | BR<br>ES<br>FEMA[1]<br>NWS[1]<br>RC<br>SCS<br>USCE[1] | BR<br>ES<br>FEMA<br>NWS<br>RC<br>SCS<br>USCE[1] |
| PLAN MAINTENANCE | CDBG[4]<br>FEMA[3] | ES<br>FEMA[1]<br>NWS[1]<br>SCS | ES<br>FEMA[1]<br>NWS<br>SCS |

[1]Major involvement
[2]Project Authorization
[3]Grants to states
[4]Grants
[5]Within its jurisdiction, TVA also provides significant assistance of various types.

BR - Bureau of Reclamation
CDBG - Community Development Block Grant Program, HUD
ES - Extension Service
FEMA - Federal Emergency Management Agency
NWS - National Weather Service
PHS - Public Health Service
RC - Red Cross and other volunteer agencies
SCS - Soil Conservation Service
USCE - United States Corps of Engineers
USGS - United States Geological Survey

3. **National Flood Insurance Program.** This program was created in 1968 to:

- make flood insurance available to property owners already located in floodprone areas, and
- encourage state and local governments to institute land use management that reduces development in flood hazard areas.

The Federal Emergency Management Agency administers this program. To participate, a community must adopt a program which includes

subdivision regulations, floodway area restrictions, and elevation requirements to discourage unwise development. These may be considered both preventive and corrective techniques. Communities enrolled in the National Flood Insurance Program are eligible for technical and financial assistance in reconstructing their flood-damaged properties (FEMA, 1981).

4. **Comprehensive Community Planning.** Floodplain management and flood hazard mitigation should be an integral part of the community comprehensive planning and development process. The basic responsibility for regulating floodplain use lies with state and local governments. Many local comprehensive land use plans have been developed without consideration of drainageways and floodplains. A flood disaster impacts and is impacted by every aspect of community life and planning, housing, public services, utilities, commerce, and major streets. Therefore, there is a direct relationship between flood disasters and comprehensive community planning (FEMA, 1981).

5. **Regulations to Control Floodplain Development.** Floodplain regulations represent a legal mechanism used to control development in the floodplain in an effort to reduce flood damage. This is accomplished by restricting development in hazardous areas and/or by providing performance standards for construction there. Some potential floodplain regulations are listed below:

<u>Floodplain Ordinances</u>

Local governments are required to adopt land use regulations which restrict landuse within designated floodplains. If these adopted

regulations meet minimum state and federal standards and are actively enforced, they serve as an effective tool to mitigate flood hazards (Montana Disaster & Emergency Services Division, 1986).

### Zoning

"Zoning divides the area under the jurisdiction of a government unit into specified areas for the purpose of regulating (a) the use of structures and land, (b) the height and bulk of structures, and (c) the size of lots and density of use." This tool may be used to regulate land use in flood hazard areas (e.g., specification of minimum floor elevation) (FEMA, 1981).

### Subdivision Regulations

"Subdivision regulations guide the process of land division to assure that lots are suitable for intended use without putting a disproportionate burden on the community." They often require (a) installation of adequate drainage, (b) delineation of flood hazard areas on the plat, (c) avoidance of encroachment into floodplain areas, (c) determination of the most suitable means of elevating a building above potential flood height, and (e) consideration of the selected flood protection elevation when siting streets and public utilities (FEMA, 1981).

### Building Permits and Codes

Building codes dictate building design and use of construction materials. They can reduce structural flood damage by such means as: (a) requiring adequate anchoring to prevent mobile home flotation during floods, (b) setting minimum protection elevations

for the first floor of structures, (c) requiring use of building materials that will not deteriorate when wetted, etc.

Soil Erosion and Sedimentation Control

Although they are natural occurrences, soil erosion and sediment deposition can inhibit floodwater carrying capacities of channels, bridges, and conduits increasing the possibility of flooding adjacent areas. Sediment control is practiced to prevent or reduce deposition damage both on and off the development site. Construction of sediment settling basins is one technique for mitigating this problem. Effective erosion control techniques include securely anchoring railroad ties to the slope, the placing of riprap (large broken rock) or the use of gabion (groups of rock bundled together with wire) (FEMA, 1986).

Stormwater Runoff Controls

Stormwater runoff regulations can require on-site stormwater detention/retention ponds for new development. The purpose of these regulations is to require that flood flows be directed to catchment basins in an effort to counteract the increase in flood peak heights which result from reducing the ground surface available to absorb stormwater runoff.

6. **Drainage and Flood Control Criteria.** Improperly designed drainage structures and the failure of those structures (bridges, channels, culverts, and embankment protections) often cause flood damage. Urban drainage and flood control criteria may be developed as a separate manual or handbook, or included in the community

subdivision regulations. These criteria will be used by public agencies and design engineers.

7. **Master Drainageway Planning.** The goal of master drainageway planning is to reduce the flood hazard in a specific drainage basin or floodplain. Steps involved in the development and implementation of a master drainage plan include data collection (land uses; drainage routes; hydrology; capacities of existing facilities, floodplain limits; and impacts on adjacent properties), conceptual design (development and review of all reasonable alternatives), and master planning (describes in detail the recommended alternative).

8. **Public Acquisition of Floodprone Lands.** There are generally two types of acquisition of undeveloped floodprone lands: a) purchase of fee title; and b) acquisition of land use easement (FEMA, 1981). Once acquired, some of the beneficial aspects of flooding may be realized. Benefits of flooding and floodplains include the natural storage of floodwaters, filtering or dilution of pollutants which enter the waterways, flushing of nutrients in river systems, preservation of wetlands, decreasing runoff having direct access to the waterway, enhancement of recreational opportunities, recharging of groundwater, and maintaining the river ecosystem by providing breeding, nesting, feeding and nursery areas for fish, migrating waterfowl and others (National Science Foundation, 1980). The technique of public acquisition assures that no future structural development will be damaged by flooding. Acquisition of floodprone lands is more expensive than

regulating their use, however, acquisition may well be less expensive than structural protection of these areas or rehabilitation following a flood event (FEMA, 1981).

9. **Community Policy Regarding Provision of Public Facilities and Utilities in Floodplain Areas** (Capital Improvements Planning). Comprehensive ordinances can specify the design and location of public facilities such as water and sewer distribution systems, to minimize the risk of contamination or damage during floods (National Science Foundation, 1980).

Corrective Techniques

1. **Acquisition and Relocation**. In the event that a floodway is already developed, floodplain areas may be obtained by outright purchase or by purchasing selected development rights. (National Science Foundation, 1980). This action not only serves to break the cycle of damage and rebuilding, but also helps property owners who would like to relocate but are unable to find private buyers for their property (FEMA, 1981). Since the cost of this technique is often high, it usually can only be justified when the situation is especially urgent or it serves other community goals (FEMA, 1981 and National Science Foundation, 1980).

2. **Floodproofing**. The term floodproofing may be applied to any measure taken to reduce the vulnerability of an individual structure and its contents to flood damages. These might include: a) measures that prohibit floodwaters from entering a building, or b) utilizing space and specialized materials to reduce damages from water which enters a building. Facilities other than

buildings (bridges, roads, docks, etc.) may be floodproofed with additional anchoring, riprap protection against erosion, bank stabilization through re-vegetation, etc. (FEMA, 1981).

3. **Structural Elevation.** This mitigation technique involves raising the lowest floor of a structure above the base flood level through methods such as earth fill, concrete walls, and wood, steel or concrete posts, piles or piers. Elevation on posts or piles is the preferred method since floodwaters can flow relatively unimpeded under the structure thus reducing the likelihood of damage to adjacent properties (FEMA, 1981).
4. **Floodwalls and Levees.** As non-structural mitigation, floodwalls and levees are embankments or structures generally less than six feet high designed to keep floodwaters from inundating one or several structures (FEMA, 1981). They may often be incorporated into the landscaping of a home without altering the structure.
5. **National Flood Insurance Program.** (discussed under preventive techniques.)
6. **Disaster Contingency Planning.** It is advisable for jurisdictions that frequently suffer flood damage to develop disaster contingency and preparedness plans. Such plans provide for disaster mitigation, warning, emergency operations and rehabilitation (FEMA, 1981).
7. **Flood Forecasting and Warning Systems.** Flood forecast and warning systems provide information concerning expected flood size arrival time (FEMA, 1981). Coordinated systems can lead to substantial

reduction of property damage and loss of lives (National Science Foundation, 1980).

**Structural Mitigation**

Structural flood mitigation measures include channel modification, flood control storage reservoirs, pumping stations, bridge and culvert improvements, levees, floodwalls and dikes and other engineering approaches to controlling flood waters in order to protect man-made development from damage. Since these measures are generally well understood and programs to implement them are already sponsored by several agencies (e.g., U.S. Army Corps of Engineers, Soil Conservation Service, Tennessee Valley Authority, and the U.S. Bureau of Reclamation) they will only be briefly discussed here (FEMA, 1981).

1. **Channel Modification.** Stream channel capacity may be increased by deepening, widening or straightening the stream or by removal of obstructions. Such modifications may increase flooding downstream since they almost always reduce natural valley storage (National Science Foundation, 1980).
2. **Flood Control Storage Reservoirs.** A storage reservoir is a stream impoundment with outlets that may be controlled. Adequate storage capacity and emergency spillway capacity are essential to minimize the possibility of dam failure (National Science Foundation, 1980).
3. **Pumping Stations.** Sump pumps should be installed in the lowest areas inside a levee to ensure that water from precipitation or seepage is removed during flooding. The pump should have an

independent power source in case there is an interruption of electrical power during flooding (FEMA, 1986).

4. **Bridge and Culvert Improvements.** Bridges and culverts should be upgraded to handle maximum predicted floodflows. Inadequate structures may have the effect of restricting floodflows thus increasing flood heights and velocities downstream (Jim E. Richard Consulting Services et al, 1986).

5. **Levees, Dikes and Floodwalls.** The term levee and dike are both used to describe a long low embankment whose height is usually less than 12 to 15 feet and whose length is more than 10 or 15 times the maximum height. The terms are usually applied to embankments or structures built to protect land from flooding. If built of concrete or masonry, the structure is usually referred to as a floodwall. A floodwall, which is a more compact structure than a levee, is normally constructed where sufficient land area required for levee construction is either expensive or not available (Colorado Department of Public Safety, 1986).

Structural mitigation measures generally provide short-term solutions and are not always a cost-effective means of dealing with the problem. Non-structural measures usually offer long-term solutions but may not adequately address an immediate threat. Administrative costs may be high for non-structural measures (Jim E. Richard Consulting Services et al, 1986). Combining both structural and non-structural techniques is the most effective approach to flood mitigation (FEMA, 1981).

## Dam Failure Mitigation

Several of the mitigation techniques listed above may also minimize the risk and reduce the damages due to dam failure. Measures which should be addressed as they relate to dam failure mitigation include public education, legislation, emergency planning, and insurance.

### Public Education

The public must be made aware of dam safety problems. Information to be distributed might include a listing of which dams are considered unsafe, where they are located, what the leading causes of dam failure are and what preventive actions can be taken.

### Legislation

Dam safety rules require that specific guidelines and standards be followed in the design, construction and maintenance of dams with an impoundment capacity of 50 acre-feet or greater. These rules also require that any high hazard dam (the failure of which would likely cause loss of life within the flooded area) maintain a plan of operation for normal, flood, and emergency conditions. This plan should include operation procedures, maintenance procedures, and emergency procedures and warning plan (DNRC, 1987).

### Emergency Warning or Preparedness Plans

These plans provide detailed information on measures to be taken to protect lives and property in the event of dam failure. Inundation maps which delineate the area affected by potential floodwaters serve as the basis for planning. Lists of individuals to be notified or evacuated should be included and updated in any plan.

## Group Insurance Plans

Group insurance policies for dam owners would spread the insurance cost of coverage for economic losses caused by dam failure over an entire group of dam owners in a particular area.

The risk of dam failure continues to increase as dams deteriorate over the years and as development continues to disregard the potential hazard. Montanans must be made aware of the problem and encouraged to alleviate it before a tragic dam failure occurs (LaFrance, 1984).

Further research is needed in the following areas to enhance future flood/dam failure planning efforts:

- Comprehensive stormwater management measures that are economically, environmentally and socially cost-effective (National Science Foundation, 1980).
- Improvement of methods of estimating floodflows (White, 1975).
- Coordination of irrigation storage and flood control uses of reservoirs such that the reservoir capacity can withstand the added volume of flow in the event of a flood (Henry, 1987).
- Solution of problems concerning the functioning of warning systems and increased funding for the application of known techniques for more effective flood warnings (White, 1975).

## SUMMARY

Montana is subject to three principal types of flooding: riverine flooding, flash flooding and dam failure flooding. Because many Montanans have chosen to locate in flood hazard areas, all three flood types have historically had damaging effects. As long as people continue to develop in

these areas, whether knowingly or unknowingly, flood events will continue to take their toll.

Flood mitigation strategies should combine both structural and non-structural approaches to alleviating the hazard. Structural approaches include reservoir storage, channel modification, levees (dikes) and floodwalls, pumping stations and other engineering works designed to control floodwaters. Non-structural approaches include both preventive and corrective actions. Preventive actions involve comprehensive floodplain management techniques that prevent unwise and hazardous development of the floodplain. Corrective actions are directed at mitigating flood damages and losses which result from unwise development of flood hazard areas.

In addition to the above mentioned techniques, dam failure flooding may be mitigated through dam safety legislation, effective emergency warning or preparedness plans, group insurance plans for dam owners and increased public awareness of dam safety problems.

The flood hazard in Montana will never be subject to complete control by man but damaging effects can be substantially mitigated.

## REFERENCES


Boner, F.C., and Stermitz, F., 1967, Floods of June 1964 in northwestern Montana: Geological survey water - supply paper 1840-B. 242 pgs.

Colorado Department of Public Safety, 1986, Dam safety: An owner's guidance manual: Division of Disaster and Emergency Services, Golden, CO., 117 pgs.

Committee on Safety Criteria for Dams, Water Science and Technology Board, Commission on Engineering and Technical System, and National Research Council, 1985, Safety of dams - Flood and earthquake criteria: National Academy Press, 276 pp.

FEMA, 1981, Flood hazard mitigation - Handbook of common procedures: Interagency regional hazard mitigation teams.

FEMA, 1983, Guide for flood preparedness planning: Prepared by Flood Loss Reduction Associates, Palo Alto, CA., 66 pp.

FEMA, 1979, 1981-1985, Flood insurance studies for various Montana jurisdictions.

FEMA, 1986, Design manual for retrofitting flood-prone residential structures: Federal Insurance Administration, Office of Loss Reduction, 265 pp.

Hays, W. W. (ed.), 1981, Facing geologic and hydrologic hazards - Earth science considerations, Geological Survey Professional Paper 1240-B, U.S. Government Printing Office, Washington, D.C., p. 39-53.

Henry, J., 1987, Hazard mitigation 406 plan for FEMA-761-Dr and 777-DR: Montana Disaster and Emergency Services Division, Helena, MT.

Jim E. Richard Consulting Services, Stiller and Associates, and OEA Research, 1986, Southeast Helena Valley hazard mitigation plan: Lewis and Clark County, MT., 35 pp.

Johnson, M.V. and Omang, R.J., 1974, Floods of January 15-17, 1974, in northwestern Montana: U.S. Geological Survey Open-File Report p. 74-38, Helena, MT., 8 pp.

Johnson, M.V. and Omang, R.J., 1976, Floods of May-July 1975 along the Continental Divide in Montana: U.S. Geological Survey Open-File Report, p. 76-424, 18 pp.

LaFrance, M., 1984, Dam safety in Montana: Cooperative Extension Service, Montana State University, Bozeman, MT., 14 pp.

McDonald, G., Project Rehabilitation Supervisor, Water Resources Division, Montana Department of Natural Resources and Conservation, 1987, Personal communication.

## REFERENCES (Cont'd)


Montana Civil Defense Division, 1976, Hazard/vulnerability analysis: Montana Disaster Preparedness Program, pp. 99-103.

Montana Department of Natural Resources and Conservation, 1976, The framework report - A comprehensive water and related land resource plan for the State of Montana: Water Resources Division, V.1, 101 pp.

Montana Department of Natural Resources and Conservation, 1987, Defining the floodway and floodway fringe: High Water, A floodplain management newsletter, Floodplain Management Section, Vol. 27.

Montana Department of Natural Resources and Conservation, 1987, Dam Safety Rules (Draft): Title 36 (proposed) Chapter 25 Safety of dams, 69 pp.

Montana Disaster and Emergency Services Division, 1986, Local government guide for hazard mitigation: Helena, MT

National Science Foundation, 1980, A report on flood hazard mitigation: Washington, D.C., 253 pp.

Parrett, C., Carlson, D.D., Craig, Jr., G.S., and Hull, J.A., 1978, Data for floods of May 1978 in northeastern Wyoming and southeastern Montana: U.S. Geological Survey Open-File Report, p. 78-985, 16 pp.

Parrett, C., Omang, R.J., and Hull, J.A., 1982, Floods of May 1981 in west-central Montana: U.S. Geological Survey Water-Resources Investigations p. 82-33, 20 pp.

Paulsen, C.G. (project director), 1949, Floods of May-June 1948 in Columbia River Basin: U.S. Geological Survey Water-Supply Paper p. 1080, 476 pp.

U.S. Army Corps of Engineers, 1981, News release - National Dam Inspection Program: Public Affairs Office, Seattle, WA., 25 pp.

Wells, J.V.B. (project director), 1955, Floods of April 1952 in the Missouri River Basin: U.S. Geological Survey Water-Supply Paper 1260-B, 302 pp.

Wells, J.V.B. (project director), 1957, Floods of May-June 1953 in the Missouri River Basin in Montana: U.S. Geological Survey Water-Supply Paper 1320-B, 153 pp.

White, G.F., 1975, Flood hazard in the United States: A research assessment: Program on Technology, Environment and Man Monograph #NSF-RA-E-75-006, Institute of Behavioral Science, University of Colorado, Boulder, CO., 141 pp.

# LANDSLIDES[1]

## DESCRIPTION

Landslides (often referred to by engineers as "slope failures" and by geologists as "mass movement") are among the most common natural hazards. As with most natural hazards, they are often characterized by the catastrophic examples, such as the Hebgen/Quake Lake slide of 1959 (discussed below). Unlike most natural hazards, however, most damage is not caused by extreme events, but by uncounted (and often unreported) minor events. Slopes with the greatest potential for sliding are between 34 degrees and 37 degrees (Strahler, 1981).

Although steep slopes are commonly present where landslides occur, it is not necessary for the slopes to be long. Thus landslides are one major natural hazard that is as likely, or perhaps more likely, to occur in eastern Montana as in the mountainous western part of the state.

Two criteria are typically used to classify landslides - types of movement and types of material. The types of movement are falls, topples, slides, spreads, flows, and combinations of two or more of these. Bedrock and soils are considered the principal material types. The soils type is further divided into debris and earth.

Figure 1 taken from a Geological Survey Professional paper entitled "Facing Geologic and Hydrologic Hazards - Earth Science Considerations," defines and graphically depicts the types of landslides listed above.



---

[1] Based principally on data provided by Michael Egan, Keith W. Smith, and Edward Spotts, Graduate Students, Earth Sciences Department, Montana State University.

Landslides occur when the shearing forces exceed the resisting forces of earth materials. Several factors contribute to either increased shear stress or reduced shear strength, thus initiating the landslide process. Factors which can increase shear stress are:

- Removal of lateral support. Examples of this factor are previous slope failure, erosion by rivers, streams or tidal currents and construction.
- Loading by natural or human means. Loading may occur with the added weight of rain, hail or snow, the accumulation of loose rock fragments or volcanic material, stockpiles of ore or rock, or the weight of buildings.
- Vibrations caused by earthquakes, blasting, machinery, traffic or possibly thunder.

Some factors which contribute to reduce shear strength are:

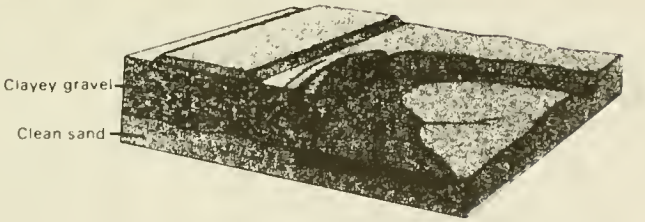
- Characteristics of the earth materials - composition, texture, structure and slope geometry.
- Material alteration through weathering and other physico-chemical reactions.
- Changes in direct water content and pore pressure and in structure (Hays, 1981).

The hazards associated with landslides are as diverse as the types of failure. Falls may damage roads or buildings at the base of a steep slope, injure climbers, or remain on a road as a hazard to drivers. Slumps usually damage utilities within or below the slide mass, but seldom cause a threat to life. Translational slides can be the most catastrophic of all

FALL (rock fall)

FALL—Mass travels most of the distance in free fall, by leaps and bounds, and rolling of bedrock or soil fragments.

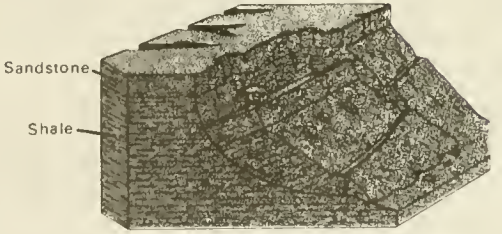
TOPPLE (debris topple)




TOPPLE—An overturning movement that, if unchecked, will result in a fall or slide

SLIDE—Movement of material by shear displacement along one or more surfaces or within a relatively narrow zone

SLIDE (rock slump)

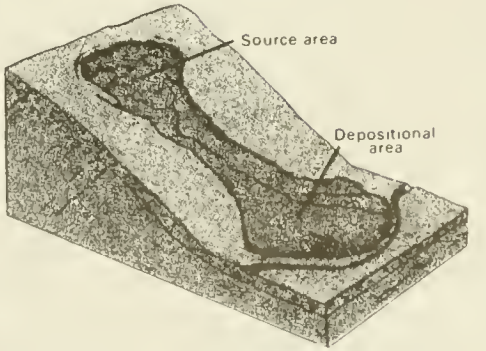



ROTATIONAL SLIDE—Movement involves turning about a point (surface of rupture is concave upward).

SLIDE (rock slide)

TRANSLATIONAL SLIDE—Movement is predominantly along planar or gently undulatory surfaces. Movement frequently is structurally controlled by surfaces of weakness, such as faults, joints, bedding planes, and variations in shear strength between layers of bedded deposits, or by the contact between firm bedrock and underlying detritus

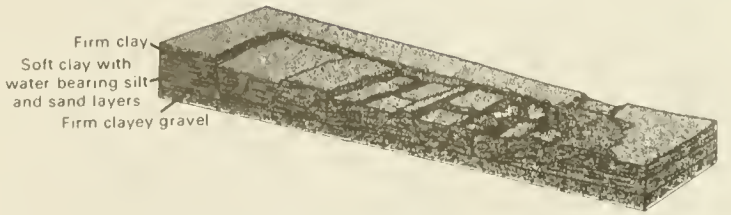
FLOW (earth flow)




(Modified from Zaruba and Mencl, 1969)

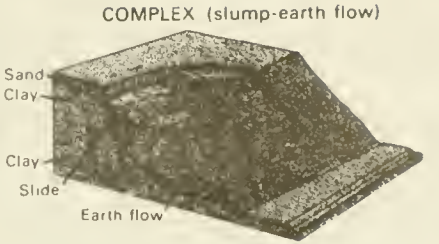
FLOW—Movement of mass such that the form taken by moving material or the apparent distribution of velocities and displacements resembles that of viscous fluids; velocity ranges from slow to extremely rapid.

LATERAL SPREAD (earth spread)




LATERAL SPREAD—Lateral extension movement of a fractured mass; some spreads are without a well-defined basal shear surface; others include extension of rock or soil resulting from liquefaction or plastic flow of subjacent material.

COMPLEX (slump-earth flow)




COMPLEX—Landslide incorporating two or more types of movement

Figure 3. Examples of landslides by type of movement.

Source: Hays, W.W., (ed.), 1981, Facing geologic and hydrologic hazards—Earth Science considerations, Geological Survey Professional Paper 1240-B. U.S. Government Printing Office, Washington, D.C. pp. 55-

landslides; in addition to presenting a local hazard to structures and utilities they can cause damage and death both far from and only slightly below the source. Flows, in addition to the above hazards, can flow around strongly-built structures, preserving them but causing damage from water and mud.

In addition to the direct hazards of a landslide moving out from under or onto structures or utilities, there is a major indirect hazard. Large slides generally do not stop moving until they reach the bottom of a valley. At that point, they serve to block streams, acting as poorly-constructed earthfill dams. Flooding due to failure of the slide dam commonly follows. Landslides which caused no significant damage during failure, such as the Gros Ventre slide of 1929, have caused major damage and deaths by the consequent slide dam failure.

**HISTORICAL OCCURRENCE AND RESPONSE:**

Much of the topography of the State of Montana was shaped by landsliding. Some slides occurred under a different climate than that which presently exists and are now stable; others have been de-stabilized by human activity or natural causes and are currently active. The evidence of past landslides is among the most important factors in the prediction of future failures (Clark and Williams, 1968).

**Pipe Organ Landslide, Beaverhead County**. The Pipe Organ Landslide is an ancient landslide that has been partially reactivated by the relocation of the Union Pacific Railroad tracks. The landslide, 4800' wide and 4400' long, occurred in volcanic and alluvial materials. The initial (prehistoric) failure probably resulted from oversteepening of the slope by the Beaverhead River, pressure resulting from excessive groundwater, and

possibly earthquake shaking. The 1965 relocation of the railroad tracks required a cut into the toe of the original slide, locally oversteepening the slope. Three slumps occurred, over the space of one year. Groundwater was determined to be a factor in the latest movement, so drainage and pumping systems were used to remove water from the problem areas. These mitigative measures stopped slide movement, at least temporarily.

**Armell's Creek, Fergus County.** The Armell's Creek slide typifies translational failures along the Missouri River. This slide, covering 20 acres, occurred within the Cretaceous Bearpaw Shale. Construction of U.S. 191, across a prehistoric slide mass, required both the addition of road fill and the blockage of existing natural drainages. The added weight and water caused failure, even during construction. Modification of the road design to include construction of a retaining wall, improvement of drainage, and unloading of the head of the slide were only partially successful in stabilizing the slide mass. Frequent road bed repairs are required due to continued movement.

**Madison Canyon Landslide, Madison County.** The 1959 Hebgen Lake earthquake triggered the catastrophic sliding of 37 million cubic yards of rock from a mountainside in to the canyon of the Madison River. The translational failure took place along foliation planes in the metamorphic rock of the canyon wall. The cutting of the canyon and the weakness of the rock set the stage for the failure; the earthquake merely controlled the time of failure. The slide mass moved down the canyon wall, blocked the Madison River, and rose about 70 feet up the far wall, covering a camp ground and killing 26 people. Prompt action by the Corps of Engineers

prevented the breaching of the slide dam by the waters of Quake Lake, averting downstream flooding. Although the mechanism of this slide is similar to others, failures of this size are (fortunately) uncommon.

Hundreds of additional slides have been discovered or observed throughout the state. The examples cited should, however, be sufficient to demonstrate the vulnerability of the state to this hazard.

**Frenchtown Landslide, Missoula County.** The Frenchtown slide represents still another reactivation of a preexisting slide mass. During the construction of U.S. 10 translational failure occurred at the contact between cemented gravels and overlaying glacial lake clays. In addition to construction activities, high groundwater pressure were blamed for slide movement. The abundance of glacial lake beds in central and western Montana and the extensive development of these flat valley floors make this slide representative of many of the smaller urban slope failures in the state.

## PREDICTION POTENTIAL FOR RECURRENCE.

Much of Montana's terrain was shaped by landslides, and it is inevitable that landslides will recur in most parts of the state. The areas of greatest susceptibility are those underlain by Cretaceous shales, with steep slopes, where the geologic structure parallels the hillslope, and where water availability is highest. The hazard decreases with deviation from those characteristics. The hazard is greatest in the spring, when more water is usually present, and during earthquakes, which may trigger the failure of unstable slopes. The variability of the hazard with structure, rock type, and terrain is such that only a site-by-site analysis will serve to delineate areas of hazard.

## STATE VULNERABILITY TO LANDSLIDES:

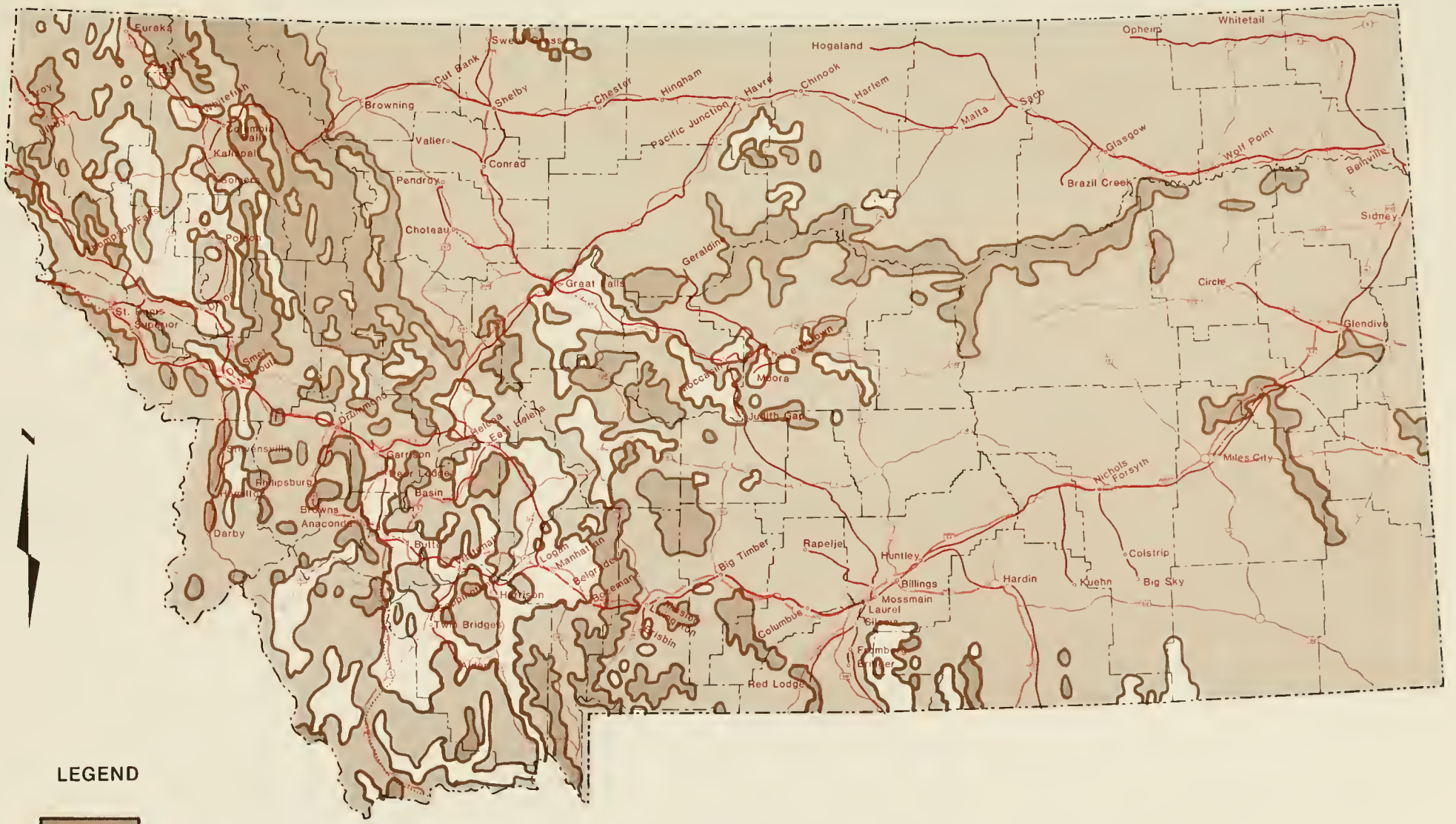
Landslides pose some degree of hazard to virtually the entire State of Montana. They become disastrous when intensive land development occurs in their proximity and people and property are endangered. It is therefore reasonable to expect an increase in potential levels of damage as the population grows unless mitigative strategies are implemented.

Figure 2 represents a compilation of maps which together indicate areas of Montana which are vulnerable to landslides. The base map showing high, moderate and low levels of susceptibility to landslides was originally developed using the Montana Computer Graphics System at Montana State University (Ford, 1978). A combination of variables such as soil types, vegetation, annual precipitation, slope and actual landslide locations was used to produce this map. Combining this map with one showing transportation corridors indicates areas of potential transportation hazards due to landslides. By adding the population density acetate overlay, those areas which pose potential hazard to people and property become visible.

## MITIGATION:

Fortunately, the prevalence of the landslide hazard has given rise to both recognition of the hazard and approaches to hazard mitigation. These approaches may be summarized as follows:

**Identification** of problem areas is considered to be "half the solution" (Gedney and Weber, 1978). Areas of present or potential instability should be mapped and analyzed by professionals.




LEGEND

- High Landslide Vulnerability
- Moderate Landslide Vulnerability
- Low Landslide Vulnerability
- Highways
- Railroads

Figure 2. Vulnerability to landslides in Montana

Sources: Ford, 1978
Department of Earth Sciences, Montana State University
Montana Highway Department
Montana Agricultural Experiment Station

**Avoidance** of problem areas, once identified, is the most efficient mode of mitigation. A program of landslide avoidance requires effective land use controls implemented by governmental decision makers with input from planners, geologists, and engineers (National Research Council, 1985). Land use in landslide-prone areas should be restricted to recreation, agriculture, or other activities which would not incur substantial losses in the event of a landslide. Low-intensity physical development is acceptable in such areas if appropriate precautions are taken (Sangrey and Bernstein, 1984-85).

**Design and Building Codes** serve as the regulatory means by which local governments may ensure desired design and construction practices. Codes may be used to regulate design of new construction as well as to modify existing structures in landslide-prone areas such that they are relatively resistant to landslide movement. Various codes have been developed on the federal, state and local government levels which may serve as models for landslide hazard mitigation (Sangrey and Bernstein, 1984-85).

**Landslide Control and Stabilization** should be undertaken only when necessary. Such efforts will generally be aimed at the contributing factors: decreasing the shearing forces and/or increasing the resisting forces of earth materials.

Reduction of the Shearing Forces can be accomplished by reducing the mass to be involved in a potential slide by stripping rock and overburden from above the likely failure plane. Such material can often be used locally as fill, thus reducing project costs rather than increasing them (Gedney and Weber, 1978).

Increasing the strength of the potential slide mass may be accomplished through several methods. The best method (Gedney and Weber, 1978; Veder, 1981) is to prevent water access to the potential failure plane, and to remove existing water. Surface drains and subsurface drains and pumps are used to accomplish this. The strength of the mass can also be increased mechanically. Buttresses, retaining walls, and berms at the toe of the potential slide will resist movement (e.g., buttresses constructed along the Beartooth Highway). Within the slide mass, unstable layers can often be "pinned" to stable materials below using reinforcing rod or reinforced concrete columns. Unconsolidated materials are less manipulatable, but can sometimes be strengthened by drainage, the addition of chemicals (salts) which increase cohesion, and the withdrawal of water using pumps, or other methods. These techniques are expensive, but can be used to advantage in certain situations (Gedney and Weber, 1978).

**Insurance** is a mitigative measure which distributes the costs of landslides over a larger population or a longer period of time. Difficulties in implementing an effective insurance program include definition of the risk, the possibility of adverse selection by the insured and the development of statistical data. The private sector is reluctant to provide such coverage, however, a public insurance program such as the National Flood Insurance Program may be a viable alternative (National Research Council, 1985).

Further research would add to the above mentioned mitigation options. Obvious needs include geologic and engineering research, the development of new mapping techniques, adoption and enforcement of appropriate building and

grading codes, more effective land use planning and management techniques, wider distribution of landslide hazard and mitigation information and investigation into the feasibility of landslide insurance. At present, landslide-related costs could be reduced simply by more effective implementation of existing capabilities (Sangrey and Bernstein, 1984-85).

## SUMMARY

Landslides occur when the shearing forces exceed the resisting forces of earth materials. Unlike most natural hazards, landslides have affected and will continue to affect both eastern and western Montana to some extent. As the State's population increases and consequent land development intensifies, this hazard poses a growing threat. It is therefore critical that local governments identify landslide-prone areas within their jurisdiction. Once identified, appropriate mitigation strategies (avoidance, design and building codes, control and stabilization, insurance) should be implemented in an effort to reduce landslide losses.

## GLOSSARY

Alluvium - Unconsolidated material of constant grain size (clay, silt, sand, or gravel) or in layers, deposited by streams.

Bedding - A planar surface that visibly separates one sedimentary rock layer from the succeeding layer.

Cretaceous - Geologic time unit between 135 and 65 million years ago; represented in Montana mainly by marine shales.

Fault - A fracture in rock across which relative displacement has occurred (see Joint).

Foliation - The parallel, planar arrangement of grains within a rock (usually metamorphic).

Joint - A fracture in rock across which no relative displacement has occurred, often caused by rapid cooling or regional stress (see Fault).

Liquefaction - Earth materials lose strength to the degree that they become a highly fluid mud.

Metamorphic - A class of rock characterized by crystal growth under conditions of high temperature and pressure; usually resistant to landslides (but see foliation).

Planar Surface - Flat surface of a rock formation .

Shearing - Form of strain in which relative motion takes place between parallel layers, each of which slides or glides past the adjacent layer, whether the substance be a fluid, plastic solid or brittle solid.

Steep Slope - Varies with material. Slopes >30 degrees are stable only for rock without joints or bedding sloping into the valley. Lower slope angles are stable for most material, but shales sloping into a valley may be unstable at slopes of <10, and water-saturated sediment at slopes of 1.

Unconsolidated - Not formed into a rock by pressure or temperature, can usually be dug with a hand shovel.

Volcanic - A class of igneous rocks formed at the earth's surface. Includes ash, tuff (solidified ash), and lava.

## REFERENCES


Clark, C. H. and Williams, D. A., 1968, Landslide Research: Montana Highway Commission, 109 pp.

Egan, M., Smith K.W., Spotts, E, 1985, An evaluation of the potential hazard of landslides in Montana: Unpublished report, Earth Sciences Department, Montana State University, Bozeman, MT 20 p.

Ford, G. L., 1978, A computer graphics system for interactive display of land Qualities and Potentials: Unpublished PhD. thesis, Montana State University, Bozeman, MT, 152 pp.

Gedney, D. S. and Weber, W. G., 1978, Design and construction of soil slopes: in R. L. Schuster and R. J. Krizek (eds.), Landslides, Analysis and Control, Special Report 176, National Academy of Sciences, Washington, D.C., pp. 172-190.

Hays, W. W., (ed.), 1981, Facing geologic and hydrologic hazards - Earth science considerations, Geological Survey Professional Paper 1240-B. U.S. Government Printing Office, Washington, D.C. pp. 55-64.

Montagne, C., 1976, Slope stability evaluation for land capability reconnaissance in the northern Rocky Mountains: unpublished PhD dissertation, Montana State Univana State University, Bozeman, MT. 229 pp.

National Research Council, 1985, Reducing losses from landsliding in the United States: Committee on ground failure hazards. National Academy Press, Washington, D.C. 41 pp.

Pariseau, W. G. and Voight, B., 1979, Rockslides and avalanches: Basic principles and perspectives in the realm of civil and mining operations: in B. Voight (ed.), Rockslides and avalanches: Elsevier, NY, v. II, pp. 1-92.

Root, A. W., 1958, Prevention of landslides: in E. B. Eckel (ed.), Landslides and engineering practice: Special Report 29, Highway Research Board, pp. 113-149.

Sangrey, D.A. and Bernstein, A.B., 1984-85, Landsliding - A hazard that can be mitigated in Ground Failure: National Research Council, Committee on Ground Failure Hazards, No. 1, Winter 1984-85. pp. 6-10.

Sowers, G. F. and Royster, D., 1978, Filed investigation: Landslides: in R. L. Schuster and R. J. Krizek (eds.), Landslides, Analysis and Control: Special Report 176, National Academy of Sciences, Washington, D.C. pp. 81-111.

## REFERENCES - Con't

Terzaghi, K., 1950, Mechanisms of landslides: in S. Paige (ed.), Application of geology to engineering practice: Berkey Volume, Geological Society of America. pp. 83-123.

Varnes, D. J., 1958, Landslides types and processes: in E. B. Eckel (ed.), Landslides and engineering practice: Special Report 29, Highway Research Board. pp. 20.47.

-----, 1978, Slope movement types and processes: in R. L. Schuster and R. J. Krizek (eds.), Landslides, Analysis and Control: Special Report 176, National Academy of Sciences, Washington, D.C. pp. 12-33.

Varnes, H. D., 1949, Landslide problems of southwestern Colorado: United States Geological Survey Circular 31, 13 pp.

Veder, C., 1981, Landslides and their stabilization: E. Jahn (trans.), Springer-Verlag, NY. 247 pp.

Ward, W. H., 1945, The stability of natural slopes: Geographical Journal, v. 105, pp. 170-191.

Zaruba, O., and Mencl, V., 1969, Landslides and their control: Elsevier, NY. 205 pp.

# AVALANCHES[1]

## DESCRIPTION

An avalanche is defined as a rapid, downslope movement of a mass of snow. An "avalanche hazard" develops whenever humans or their constructions are exposed to moving snow. Avalanches can be the cause of human deaths and injuries, damage to property, interruption of communications, and blockage of transportation routes. Avalanches occur throughout the mountains of Montana and, to a limited extent, elsewhere in the state. The avalanche hazard most directly threatens winter recreationists, homes and businesses in mountainous regions, and communication and transportation networks through-out the highlands.

Montana's borders bracket a region in which many avalanches occur. Two of Montana's numerous ski areas, Bridger Bowl and Big Sky, are respectively the second and fourth most avalanche-prone ski resorts in the entire United States (Avalanche, Notes, April 1985).

The two dominant factors causing an avalanche are an accumulation of snow and an inclined surface. Avalanches occur when the force of gravity pulling on the snowpack overcomes the frictional and cohesive forces holding the snow in place. Steeper slopes and greater masses of snow cause an increase in the effectiveness of gravitational force. Various physical characteristics within the snowpack affect the frictional and cohesive forces. The factors that contribute to this complex interaction of forces can be grouped in two categories: terrain and weather.



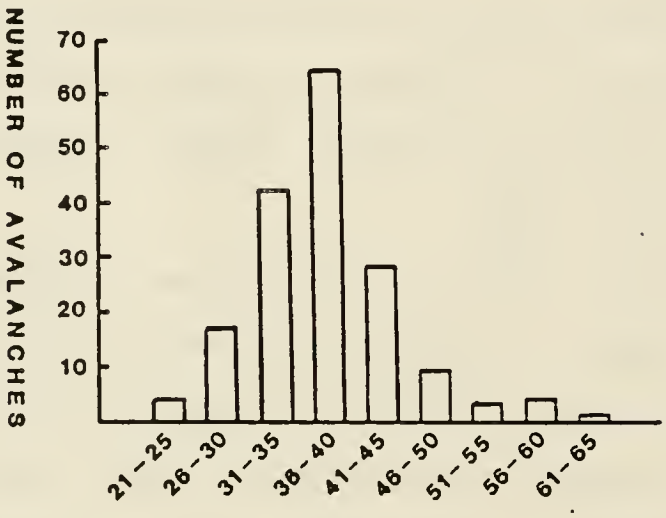
---

[1] Based principally on data provided by Robbin L. Mills, Douglas P. Richmond and Hugh D. Safford, graduate students, Earth Sciences Department, Montana State University.

## Terrain

If it is assumed that an accumulation of snow is possible anywhere in Montana, then we can evaluate the potential for hazard solely on the basis of terrain characteristics. The most important factor by far is terrain steepness. Wet snow avalanches can start on slopes of 20 degrees or less, but the optimum slope angle for avalanche starting zones is 25-45 degrees (Figure 1).

**Figure 1. Starting Zone Steepness (Degrees).** Starting zone steepness of slab avalanches from accidents in the U.S. (after Williams and Armstrong, 1984)




Slopes steeper than 45 degrees will not normally retain enough snow to generate large avalanches, but they may produce small sluffs that trigger major avalanches on the slopes below. Therefore, all slopes of 20 degrees and greater should be considered as potential avalanche sites.

Other terrain factors affecting the magnitude and frequency of avalanche activity include slope length, shape, roughness, aspect, and elevation. Slope length contributes to the force an avalanche can generate. Avalanche fatalities due to suffocation have, however, been reported on very short slopes. Slope shape and roughness contribute to the frictional forces that hold the snowpack in place. Concave and irregular slopes tend to be more stable than smooth, convex slopes. Boulders, shrubs, and trees add to slope roughness and therefore provide more stability than grass or smooth rock. Avalanches do, however, occur occasionally in heavily timbered areas. Slope elevation and aspect dictate the depth, temperature, and moisture characteristics of the snowpack that develop due to the interaction of the contributing weather factors.

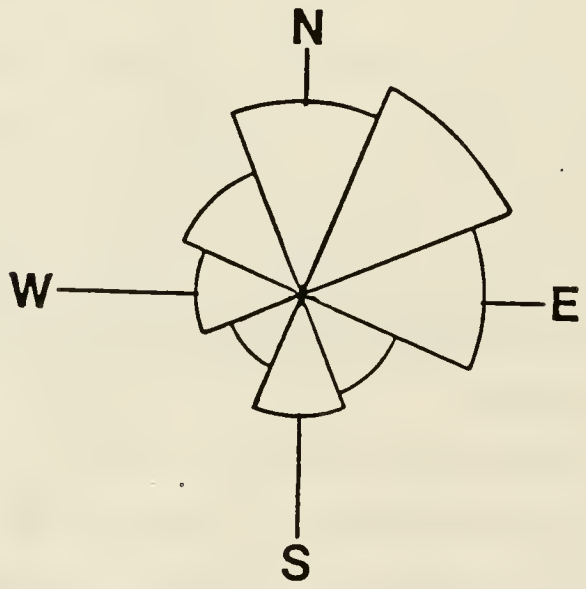
**Weather**

Weather variables, especially snowfall, affect the timing and duration of hazardous snow avalanche conditions. Over 80% of the avalanche accidents reported in the United States have occurred during or within 24 hours after a storm (Williams and Armstrong 1984). Snowfall amount, rate of accumulation, moisture content, and snow crystal types all contribute to the magnitude of unstable conditions.

Wind is another critical weather variable capable of depositing large amounts of dense snow into starting zones. Wind direction during and after a storm will determine which slopes will receive the most snow and will therefore be most susceptible to avalanche. Strong winds are capable of creating an unstable load rapidly even when little or no new snow has fallen. Because the prevailing storm track in Montana is west to east, east facing leeward slopes often receive the most snow from wind loading.

Local wind directions are highly variable, however, and any slope may be subject to wind loading. Localized studies are necessary to show particular wind direction trends. A rose diagram of starting zone aspects, based on a sample of avalanche accidents in the United States from 1950-82, suggests a higher degree of hazard on north- and east-facing slopes (Figure 2), but more importantly the diagram indicates that avalanches can occur on slopes of all aspects.

**Figure 2.** Avalanches classified by starting zone aspect. Based on a sample of avalanche accidents in the U.S. from 1950 - 1982 (after Williams and Armstrong, 1984).




Temperature is a weather factor that affects the physical nature of the snowpack. Low air temperatures over a thin, permeable snowpack cause a temperature gradient change weakening the snowpack and leading to an ongoing avalanche hazard as subsequent storms add to the snow load above this weak

layer. This condition is most prevalent on north-facing slopes during winters with severe or prolonged low temperature events. High temperatures can also contribute to avalanche hazard by melting snow and reducing friction by increasing pore pressure in the snowpack. This condition develops best on south-facing slopes, and the hazard is highest during the warmest part of the day.

The complex interaction of all these weather and terrain factors contributes to the location, size, and timing of avalanches. In the absence of detailed scientific observation, any accumulation of snow on a slope steeper than 20 degrees should be considered a potential avalanche hazard.

## HISTORICAL OCCURRENCE AND RESPONSE

Through illustration of actual examples, the analysis of specific avalanche events can be made. The lessons taught by the following incidents can aid in preparation for future events of similar nature and magnitude. Most of the examples presented are from "The Snowy Torrents," a three volume U.S. Forest Service publication devoted to cause and effect analysis of specific recorded avalanche events throughout the United States. Discussion of the following avalanche events is organized such that occurrences are grouped according to whether they resulted in injury or death, property damage, damage to communication lines and transportation routes. The locations of the following incidents are shown in Figure 3.

On March 16, 1969, an avalanche swept four (4) people, a car and a pickup truck off a logging road into the Blackfoot River about 18 km northeast of Missoula. The car had been partially buried by a smaller avalanche minutes before. Not knowing that avalanches often only release a fraction of the unstable snow, the victims of this unfortunate accident

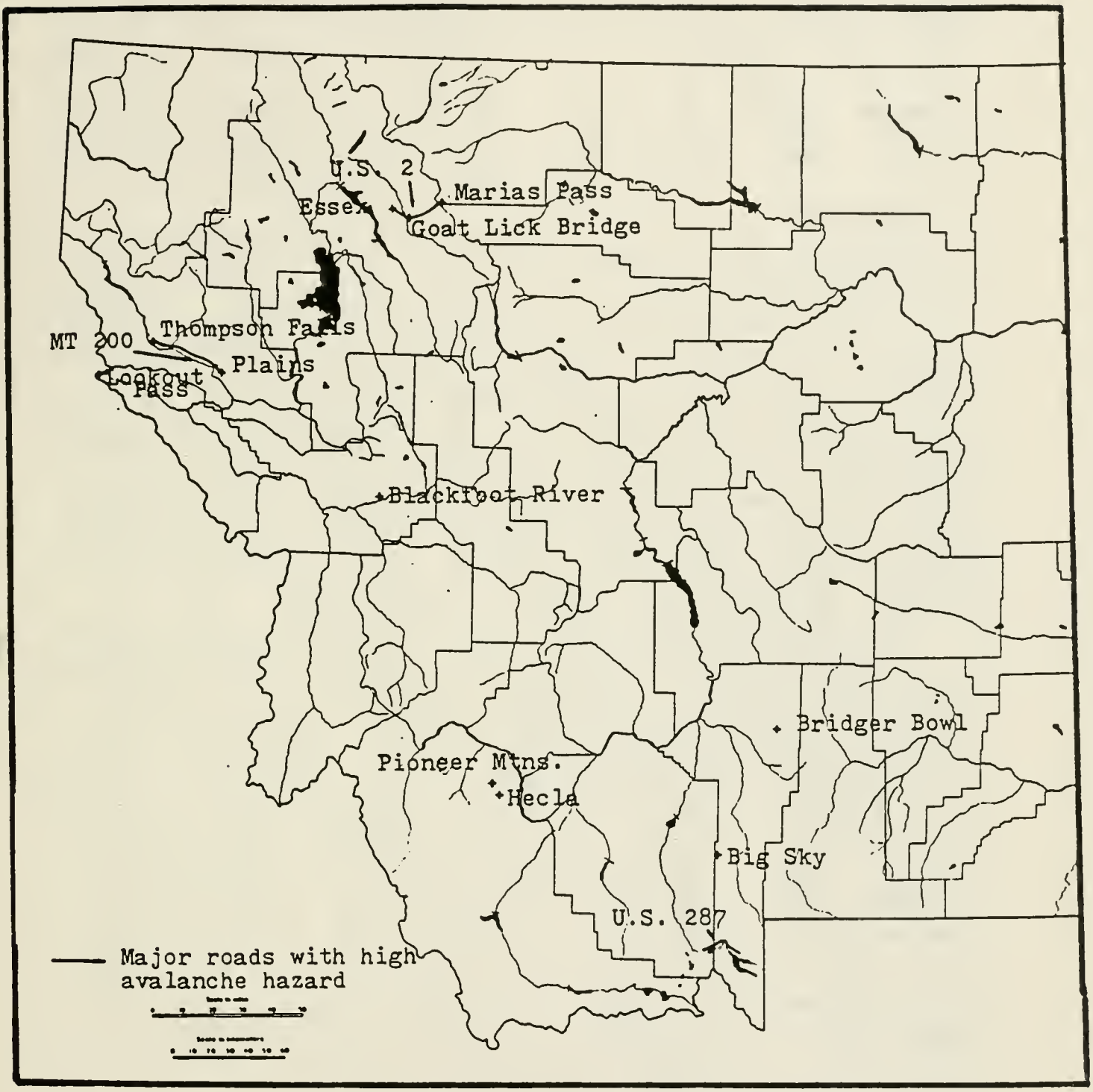



Figure 3. Histocial record - avalanche accident locations (Mills, Richmond and Safford, 1985)

placed themselves in a precarious situation by remaining in the slide path. One of the four passengers lost his life in this incident. Two or more avalanches occurring on the same path over a short period of time are relatively common. This hazard is one which must be recognized, especially by rescue groups.

On March 23, 1975, a snowmobiler was caught by an avalanche, and killed 20 km west of Melrose, Montana in the Pioneer Mountains. He and his companions were traversing an obvious avalanche path at midtrack when the entire slope fractured. Fortunately, these snowmobilers were far enough apart at the time of the slide that all, other than the victim, were able to quickly bring themselves to safety out of the reaches of the sliding snow. Obvious avalanche tracks should be avoided. If a traverse is absolutely necessary, the path should be crossed at the top or bottom

Situations of prime concern are those in which property is located directly within areas of high avalanche hazard such as at the base of a slide path. During the winter of 1893, an avalanche demolished a house at Hecla, Montana, in the Pioneer Mountains, killing five people. The house had been built at the base of a large avalanche track (Williams and Armstrong, 1984). Building without regard to avalanche hazard is commonplace, even at ski areas. In February 1968, a major avalanche at Bridger Bowl ski area destroyed the motor room for the newly installed "Alpine" chairlift. In addition, the bullwheel and unloading ramp were both damaged and one of the lift operators was buried to his chest. This slide provoked the implementation of a more complete program of avalanche control at Bridger Bowl to prevent further accidents of this nature (Williams, 1975).

Of the four major avalanche hazards, the interruption of communications lines probably occurs most frequent. Examples of slides knocking out power and telephone lines are so commonplace as to not warrant specific mention. Places of highest hazard included ski areas, mountain passes, and other areas where transmission lines cross avalanche paths.

In regions where important highways or railroads cross areas subject to frequent snowslides, losses resulting from blocked roads, buried railroad tracks, and destroyed bridges can reach into the millions of dollars.

Perhaps the most dramatic example of an avalanche blocking a transportation route occurred near Essex, Montana on February 13, 1979, along U.S. Highway 2 just inside Glacier National Park. During the week previous, local air temperatures had changed rapidly from very low to very high. Heavy, wet snow fell throughout February 12th, and had changed to rain by the morning of the 13th. As a result, the snowpack had become very unstable. On that morning a 220 ton, 112 feet (34 meter) long bridge was carried by an avalanche 500 feet (150 meters) down aptly named Snowslide Gulch and deposited in the river valley below, 380 feet (115 meters) south of the avalanche path centerline (Martinelli, 1982). The loss of this bridge necessitated a 350 mile (565 km) detour for all east-west traffic in northern Montana. Damage was estimated at $1,000,000, but transportation losses due to delays and rerouting amounted to several million more. On the same day, eleven slides crossed railroad tracks in the immediate area and three others hit Highway 2 (Williams and Armstrong, 1984). Luckily, half of the avalanches which reached the tracks were rendered harmless by snowsheds which had been constructed just for that purpose. The high hazard on this day spawned what is known as an avalanche cycle, a great number of snow-

slides occurring in the same locality due to a common weather pattern or snow condition. Avalanche cycles are periods of extremely high avalanche hazard.

Where railroads must cross mountain passes an extremely high hazard is likely to exist. On February 6, 1957, a Northern Pacific freight train was crossing Lookout Pass, between St. Regis, Montana and Wallace, Idaho when an avalanche released on a steep slope above the tracks. The snow caught the lead engine, lifted it off the tracks, and carried it 80 feet (25 meters) downhill. Luckily, although the engine was damaged, no one was seriously injured (Gallagher, 1967). This same area was the scene of an avalanche that caused the derailment of a train in 1936 and killed two people.

Snow avalanches constitute a primary winter hazard to the people of Montana. The historical record points to the variety of terrains and localities in which avalanches occur. This pervasive hazard can be minimized when treated with the correct degree of intelligence and awareness.

## PREDICTION POTENTIAL FOR RECURRENCE

Many avalanche paths show recognizable signs of previous activity. The most obvious sign is a treeless swath down a forested mountain side ending in an irregular fan shaped clearing where the slope flattens out. Within the clearing there may be trees and other debris carried down by the avalanches. The trees that are still standing are battered and may have no branches on the uphill side. A new generation of trees in the slide path may help to estimate the time since the last destructive avalanche. The removal of trees by one avalanche clears the way for successive avalanches to extend the slide path further downslope.

Many potential avalanche paths do not show these signs of previous avalanche activity. These paths may be in treeless or sparsely forested areas. Some of them may rarely avalanche because they are located where snow loading is uncommon due to elevation or aspect. Remember: if a slope exceeds 20 degrees, the potential exists for avalanches whenever an unstable snowpack accumulates.

Since most avalanches are directly linked to storms, the occurrence of a winter storm is a good sign of the onset of avalanche hazard. Larger storms will create a more severe hazard. High winds associated with snowfall are especially effective at loading snow in avalanche starting zones. Winds can often create an avalanche hazard without any associated snowfall by transporting and redepositing older snow onto avalanche paths. Masses of snow overhanging ridges or gullies indicate that wind loading has taken place on the slopes below, and these cornices may grow large enough to fall off and trigger avalanches.

The most certain sign of avalanche hazard is avalanche activity. Usually when one slope is hazardous, many of the nearby slopes are also hazardous. So whenever one avalanche is observed, many more should be expected nearby. The historical record of avalanche accidents cites numerous cases where rescue parties searching for avalanche victims have themselves become victims of the same avalanche cycle.

Besides storms, wind, and current avalanche activity, there are many more subtle signs of developing snowpack instability which the trained observer can use to assess the current avalanche hazard. These signs include visible cracks in the snow surface and audible settling sounds that indicate failure of a weak layer within the snowpack. By digging snow pits,

the trained observer can make periodic close inspections of the snowpack near starting zones to monitor the amount of snow accumulated and to estimate the cohesive strength of the various snow layers. By observing changes in the snowpack throughout the winter, the observer can often recognize the onset of instability. This improves hazard prediction beyond the simple techniques of assuming high avalanche hazard whenever there is a major storm or wind event.

The probability of avalanche recurrence is closely related to the probability of large storms. Those avalanche paths that commonly experience loading from storms because of their elevation and aspect may avalanche several times during a given winter. These are the easily recognized avalanche paths that have developed an obvious track and runout zone. Other steep slopes may rarely slide because normal winds tend to remove snow from their starting zones or because they are located in places that rarely receive sufficient amounts of snow. These slopes can be very dangerous when unusual conditions create a hazard because such hazard often goes unrecognized.

Certain weather conditions may have a strong influence on the development of future avalanche activity in a given winter. One common condition in Montana is a period of severe low temperature in early winter. This creates a temperature gradient within the snowpack, which develops a weak layer that often persists throughout the rest of the winter. This may cause many avalanches as later storms increase the snow load on the weak layer. When avalanches do occur on a temperature gradient layer, the snowpack that remains on the slope after the slide is very thin and thus more susceptible to future development of a new temperature gradient layer.

In other winters without early low temperature events, a dense, stable base may develop, and fewer avalanches may result. Temperature and snow conditions in the early winter months, therefore, have a profound influence on snowpack stability for the remainder of the winter.

Another type of weak layer can develop on cold, calm nights when a layer of surface hoar crystals grows on the snow surface by a similar process to the development of dew. These fragile crystals are often destroyed by wind or sun, but when they are buried and preserved in the snowpack, they create a very weak layer that can cause major avalanches later in the winter. According to Dr. John Montagne of Montana State University, one such layer was responsible for a fatal avalanche accident in the Hyalite Mountains south of Bozeman, Montana in 1982.

An additional important condition that influences avalanche hazard is the development of a hard, smooth sliding surface within the snowpack. This can develop between storms when the sun melts the snow surface creating an icy crust, or when winds compact and polish the snow surface. Later storm accumulations will avalanche easily on this surface, polish it further, and expose it again to repeat the cycle. These conditions and other developments within the snowpack coupled with variable amounts of snowfall in differing winters lead to a wide variation in the location, size, and frequency of avalanches from one winter to the next.

## STATE VULNERABILITY TO AVALANCHES

On a statewide scale, general areas of avalanche hazard can be identified on the basis of topographic and meteorologic characteristics. The most critical factors to consider in assessing vulnerability to avalanche are slope angle and snowfall (aspect, wind speed and direction,

temperature, slope length, and other variables subordinate). The Avalanche Vulnerability Map for Montana (Figure 4) is a weighted compilation of these two major variables (Ford, 1978) superimposed on a map of transportation routes. By adding the population density acetate overlay, those areas which pose potential hazard to people and property become visible.

This map serves to indicate areas where the hazard may exist. It does not represent site-specific conditions. As such, danger may exist at isolated sites within "low hazard" areas, and sites within "high risk" areas may be relatively safe.

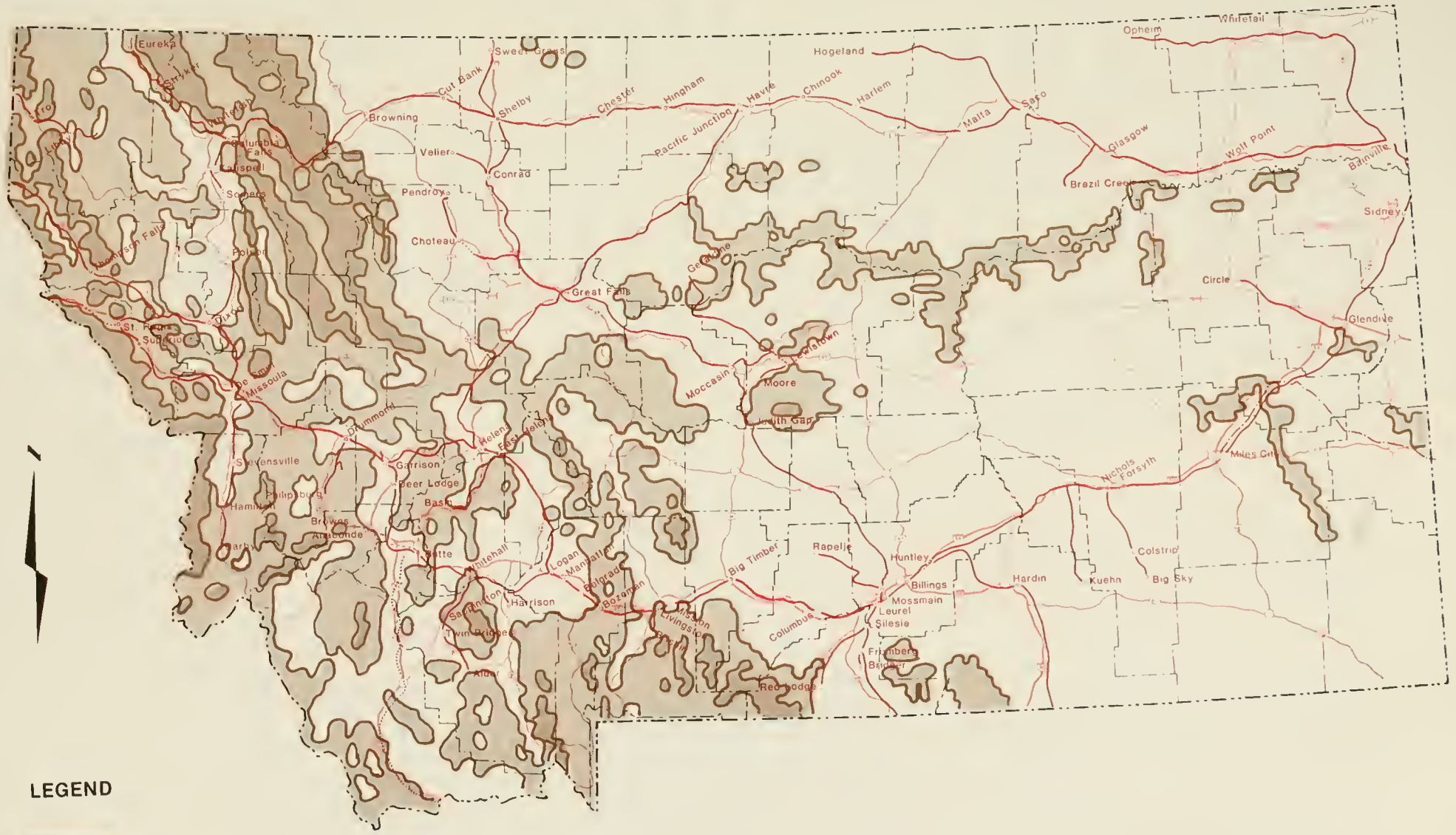
Mountainous areas show up well on the map, with the steep, snowy ranges of western Montana particularly prominent. Note that a significant hazard exists in the dissected regions adjacent to many of the major rivers of eastern Montana. Although it is probably unnecessary to zone these areas to reduce the danger of avalanches, it would be wise to have emergency plans available during blizzard conditions.

Winter recreation areas, with their high seasonal population increase, compound hazard vulnerability. County officials should be aware of winter recreation areas within their jurisdiction and plan accordingly.

With population increase and the accompanying increase in winter use of Montana's forests and parklands, avalanches pose a growing threat to people and property. The adoption of appropriate mitigation strategies is necessary to counteract this threat.

## MITIGATION

Mitigation of avalanche related problems begins with hazard recognition. This is accomplished by determination of potential avalanche




LEGEND

High Avalanche Vulnerability

Moderate Avalanche Vulnerability

Low Avalanche Vulnerability

Highways

Railroads

Figure 4 Vulnerability to avalanche in Montana.

Sources: Ford, 1978
Department of Earth Sciences, Montana State University
Montana Highway Department

sites, and then by evaluation of existing hazards through monitoring of the snowpack and weather conditions. This evaluation or hazard forecasting is an inexact science involving the complex interaction of all the causative factors. Hazard forecasts become more reliable with time as scientists develop a better understanding of a given area through continued observation. Help is available through organizations such as ski areas, where avalanche workers have gained practical experience, and also through Montana State University where the departments of Earth Science and Civil Engineering and Engineering Mechanics have gained international recognition for research work in snow science.

The following outline is a list of suggested measures for mitigation of the avalanche threat to winter recreationists, homes and communities, economic enterprises and transportation and communication systems. Some of these measures are then discussed in more detail. It should be noted that an accurate assessment of potential hazard before locating construction projects will help determine safe locations. This can eliminate some of the need for further measures, and it can save time, money, and lives in the long run.

**Winter Recreationists**

1. **Educate the public.**

Public awareness can be improved through media exposure, community workshops, employee training sessions, and university courses.

2. **Erect warning signs.**

Signs can be erected at entrances to hazardous areas to warn skiers, snowmobilers, and highway travellers.

3. **Establish a state avalanche forecasting center.**

Many mountainous areas of the western United States presently have avalanche forecast centers which issue daily avalanche hazard reports over television and radio stations as well as having call-in numbers. The benefits gained from having such a center include: availability of information on current avalanche hazard, increased public awareness through educational efforts by forecast center personnel, and a decrease in avalanche related accidents. One example is the Utah Avalanche Forecast Center which serves people in the Salt Lake City area and has greatly reduced the number of avalanche accidents in the nearby mountainous regions. A Montana avalanche forecasting center would provide a valuable service to the growing number of winter outdoor recreationists and to the county, state and federal personnel who manage the hazardous areas.

4. **Establish rescue plans.**

Most avalanche rescues are conducted by county sheriff or search and rescue personnel, and most counties in Montana should have a written rescue plan. This plan should outline the methods that will be used to conduct a safe and organized rescue effort. It should include the location of necessary equipment and the names of individuals or groups that can be called in to help (such as snowmobile groups, ski patrols, and avalanche rescue dog owners). It should also include provisions for making important avalanche hazard evaluations to prevent accidents involving rescue personnel.

Homes and Communities

1. **Research potential hazard before construction**

Potential hazard can be evaluated on an individual site basis, or a regional assessment can be made, which can then be used to write zoning ordinances that will prevent construction in known avalanche paths.

2. **Monitor Hazard and issue warnings or evacuations**

Avalanche hazard can be best monitored by a trained scientist who studies the snowpack development and the weather conditions in the immediate vicinity throughout the winter. He or she can then keep the public informed and warn them when hazardous conditions develop. Studies of this type could be coordinated through a state avalanche forecasting center.

3. **Establish a safety plan**

A safety plan should contain: provisions for hazard monitoring, a plan for informing the public, an evacuation plan, a rescue plan, and an avalanche control plan which may include the use of explosives and man-made barriers.

Economic Enterprises **(ski areas, mines, etc.)**

1. **Evaluate before construction.**

(See Homes and Communities 1. above) Special care should be taken to locate any living quarters, work places, ski lifts, or other places where people will gather, in the safest possible locations.

2. **Educate personnel.**

Conduct periodic workshops and post bulletins to insure that employees are well informed of potential hazard and of emergency procedures.

3. **Erect warning signs in known avalanche areas.**

4. **Establish safety plan.**

(See Homes and Communities 3. above) A supply of avalanche rescue equipment should be kept on hand, and personnel should be trained in its use. Live rescue of avalanche victims depends on quick, effective action by those at the scene.

5. **Monitor avalanche hazard and allow for temporary closures.**

(See Homes and Communities 2. above) The snow scientist who monitors the avalanche hazard should be in communication with the manager of the enterprise so that the area can be closed and evacuated if conditions become severe.

**Transportation and Communication Systems**

1. **Evaluate before construction.**

The cost of avalanche control, snow removal, and repairs may be higher in the long run than the added cost of adjusting route locations to avoid potential avalanche paths.

2. **Erect defense structures.**

Defense structures include barriers, sheds, snow fences, and other structures. Photos and descriptions of many types of structures are shown in the Avalanche Handbook (Perla and Martinelli, 1976).

3. **Establish safety plan (See previous discussion of safety plans)**

4. **Establish alternate emergency routes.**

If roads or communication lines must be placed in areas of potential avalanche activity, some provisions should be made for emergency routes when the main routes are closed or damaged by avalanches.

Some mitigating actions are important to all four of the above categories. These actions are: terrain analysis so that major hazards can be recognized and avoided; development of a safety plan; education of everyone involved; and observation throughout the winter to detect developing hazards before accidents happen. By taking these steps, we can minimize the risk of future snow avalanche accidents in Montana, and provide a valuable service to the growing number of recreationalists, travellers, and workers in the mountains of Montana.

## SUMMARY

Avalanches occur throughout the mountains of Montana, and to some extent, elsewhere in the state. Avalanches become hazardous when they threaten human life, property, communications, and transportation corridors. This hazard occurs when the force of gravity on the snowpack overcomes the frictional and cohesive forces holding the snow in place. The historical record of avalanches in Montana demonstrates the variety of terrains and localities in which incidents have occurred and in which they are likely to occur in the future.

Areas of the state which are vulnerable to avalanche are primarily the mountains of western Montana, and dissected regions next to many rivers in the eastern part of the state. The hazard increases with coincident location of population centers, winter recreation areas, and transportation and communication corridors.

Mitigation strategies include hazard recognition, establishing state avalanche forecasting centers, hazard monitoring and warning, pre-

construction research in avalanche-prone areas, establishing safety plans, erecting defense structures, delineating alternate emergency routes and educating the public. Implementation of mitigation strategies will help reduce losses to future avalanches.

## REFERENCES


Atwater, M.M., 1968, The avalanche hunters: Philadelphia, Macrae Smith, 223 pp.

Bryson, S., 1976, Search and rescue dog training: Pacific Grove, CA, Boxwood Press, 213 pp.

Ford, G.L., 1978, A computer graphics system for interactive display of land qualities and potentials: unpublished Ph.D dissertation, Montana State University, Bozeman, MT, 152 pp.

Fraser, C., 1978, Avalanches and snow safety: New York, Scribner, 260 pp.

Gallagher, D., ed., 1967, The snowy torrents: Avalanche accidents in the United States, 1910-1966: Alta, UT, U.S.D.A., Forest Service, Alta Avalanche Study Center, 144 pp. (Out of print, available in libraries).

Glen, J.W., Adie, R.J., Johnson, D.M., and Homer, D.R., eds., 1980, Symposium on snow in motion: Journal of Glaciology, v. 26, 527 pp.

Gray, D.M., and Male, D.H., eds., 1981, Handbook of snow: Principles, processes, management and use: Toronto, Pergamon Press, 776 pp.

La Chapelle, E.R., 1969, Field guide to snow crystals: Seattle, University of Washington Press, 101 pp.

La Chapelle, E.R., 1979, The ABC of avalanche safety: Seattle, University of Washington Press, 56 pp.

Martinelli, M., Jr., 1974, Snow avalanche sites: Their identification and evaluation: Washington, D.C., U.S.D.A. Agriculture Bulletin 360, 26 pp.

Martinelli, M., Jr., 1982, The Goat Lick Bridge avalanches of 1979 and 1982, in Abstracts with program, International snow science workshop: Montana State University, Bozeman, MT, pp. 1.

Mills, R.L., Richmond, D.P., and Safford, H.D., 1985, Natural hazards of Montana - Snow avalanches: unpublished report, Earth Sciences Department, Montana State University, Bozeman, MT, 25 pp.

Montagne, C., Munn, L.C., Nielsen, G.A., Rogers, J.W., and Hunter, H.E., 1982, Soils of Montana: Montana State University, Montana Agricultural Experiment Station Bulletin 774, 95 pp.

Perla, R.I., 1980, Avalanche release, motion, and impact, in Colbeck, S.C., ed., Dynamics of snow and ice masses: New York, Academic Press, pp. 397-462.

Perla, R.I., and Martinelli, M., Jr., 1976, Avalanche handbook, Washington, D.C., U.S.D.A. Agriculture Handbook 489, 254 pp.

Setnicka, T.J., 1980, Wilderness search and rescue: Boston, Appalachian Mountain Club, 640 pp.

Stethem, C.J., and Schaerer, P.A., 1979, Avalanche accidents in Canada I: A selection of case histories of accidents, 1955-1976: Ottawa, Ontario, Division of Building Research, Paper 834, National Research Council, 114 pp.

Williams, K., 1975, The snowy torrents: Avalanche accidents in the United States, 1967-1971: Jackson, WY, Teton Bookshop Publishing Co., 190 pp.

Williams, K., 1985, Avalanche notes: Fort Collins, CO, U.S.F.S. Rocky Mountain Forest and Range Experiment Station.

Williams, K., and Armstrong, B., 1984, The snowy torrents: Avalanche accidents in the United States, 1972-1979: Jackson, WY, Teton Bookshop Publishing Co., 221 pp.

# EARTHQUAKE[1]

## DESCRIPTION

Earthquakes pose by far the largest single-event natural hazard faced by Montana. They may affect large areas, cause great damage to structures, cause injury, loss of life, and alter the socioeconomic functioning of the communities involved (Working Group, 1978). The hazard of earthquakes varies from place to place, dependent upon the regional and local geology. Western Montana contains a zone of high seismicity, the Intermountain Seismic Belt (See Figure 1), which covers parts of Nevada, Arizona, Utah, Wyoming and Idaho (Sbar, et al., 1972). In Montana, this seismic belt trends north from Yellowstone National Park to Helena, then heads northwest, terminating beyond Flathead Lake. Most of the earthquake activity in the state occurs within this zone.

Earthquakes occur along faults, which are fractures or fracture zones in the earth across which there may be relative motion. If the rocks across a fault are forced to slide past one another, they do so in a "stick-slip" fashion; that is, they accumulate strain energy for centuries or millennia, then release it almost instantaneously. The energy released radiates outward from the source, or focus, as a series of waves - an earthquake. The primary hazards of earthquakes are ground breaking, as the rocks slide past one another, and ground shaking, by seismic waves. Secondary earthquake hazards result from distortion of surface materials such as water, soil, or structures (Table 1).



---

[1] Based principally on data provided by Donalee Esp and John Melesh, graduate students, Department of Earth Sciences, Department Montana State University, and William P. Clement, graduate student, Geology Department, University of Montana.

The hazard of ground breaking is confined to a single fault or a narrow zone of multiple faults. Within the fault zone, which is generally less than 0.5 miles wide (Witkind, 1972), most structures will be destroyed and utilities will be cut. In the case of a moderate, small or deep earthquake, ground breaking may not occur at all.

**Figure 1.** Illustrative Zone Map of the United States. Seismic zones are identified with the numbers 0 through 4. Zone 4 defines regions of major risk, with successively lower numbers defining regions of lesser risk (ANSI, 1982).

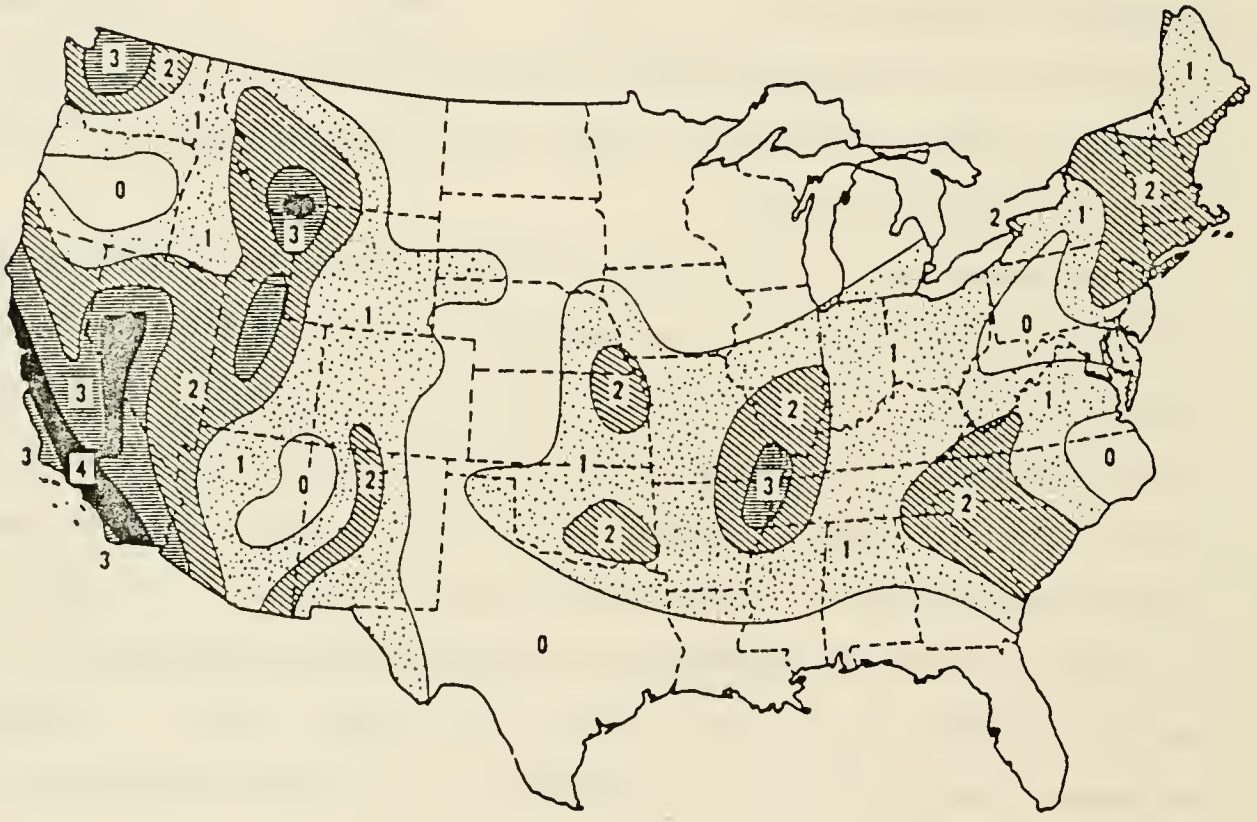


**Table 1.** Hazards of earthquakes (Esp and Melesh, 1985).

| PRIMARY | SECONDARY | |
|---|---|---|
| | NATURAL | HUMAN |
| Ground breaking<br>Ground Shaking | Seiche<br>Snow Avalanche<br>Landslide<br>Liquefaction of Soils | Utilities ruptured<br>Highways ruptured<br>Highway bridges fail<br>Fires ignited<br>Structures destroyed<br>Dam failure/flood<br>Water tanks toppled |

In contrast, ground shaking may affect areas 65 miles or more from the epicenter (the point on the ground surface above the focus). As such, it is the greatest primary earthquake hazard. Ground shaking may cause seiche, the rhythmic sloshing of water in lakes or bays. This phenomenon occurred during the Hebgen Lake earthquake. Waves of water were forced out of the Madison River by ground motion and by the landslide which created Earthquake Lake. Rhythmic waves of water overtopped Hebgen Dam. It may also trigger the failure of snow (avalanche) or earth materials (landslide). Ground shaking can also change the mechanical properties of some fine grained, saturated soils, whereupon they "liquify" and act as a fluid (liquefaction). The dramatic reduction in bearing strength of such soils can cause buried utilities to rupture and otherwise undamaged buildings to collapse.

The major form of damage from most earthquakes is damage to construction. Bridges are particularly vulnerable to collapse, and dam failure may generate major downstream flooding. Buildings vary in susceptibility, dependent upon construction and the types of soils on which they are built. Fires caused by ruptured gas mains may also destroy structures.

The damage caused by both ground breaking and ground shaking can lead to the paralysis of the local infrastructure: police, fire, medical, and governmental services. As with many catastrophes, the worst hazard to the survivors is their own shock and inability to respond to the necessity for prompt, effective action.

Earthquakes are measured according to their intensity (observed effect) and magnitude (energy released). Intensity is an indication of an earthquake's apparent severity at a specified location, as determined by experienced observers. For seismologists and emergency workers, intensity becomes an efficient, though subjective, shorthand for describing the effects of an earthquake in a given area. Magnitude expresses the amount of energy released by an earthquake as determined by standardized recording instruments.

The Modified Mercalli Scale is the method most commonly used in the United States for measuring earthquake intensity. This 12 tier scale (See Table II) ranks observed effects from I, "felt only under especially favorable circumstances" to XII, "damage total" (Montana Civil Defense Division, 1976).

The magnitude of an earthquake is most commonly measured through the use of the Richter Scale. Earthquake magnitudes describe the subject on an absolute, not an arithmetic, scale. An earthquake of magnitude 8, for example, is ten times stronger than a magnitude 7 earthquake, 100 times stronger than a magnitude 6 earthquake, and so on. There is no highest or lowest value, and it is possible here, as with temperature, to record negative values. The largest earthquakes of record were rated at magnitude 8.9; the smallest, about minus 3. Preliminary magnitude determinations may

vary with the observatory, equipment, and methods of estimating -- the Alaska earthquake of March 1964, for example, was described variously as magnitude 8.4, 8.5, 8.6 by different stations.

Table 2. Modified Mercalli Intensity Scale of 1931 (Qamar and Stickney, 1983)

| | |
|---|---|
| I. | Not felt except by a very few under especially favorable circumstances. |
| II. | Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. |
| III. | Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize the motion as an earthquake. Standing motor cars may rock slightly. Vibration similar to that of a passing truck. |
| IV. | During the day, felt indoors by many; felt outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation similar to that of a heavy truck striking building. Standing motor cars rock noticeably. |
| V. | Felt by nearly everyone; many awakened. Some dishes and windows broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop. |
| VI. | Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of falling plaster or damaged chimneys. Damage slight. |
| VII. | Everyone runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built, ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motor cars. |
| VIII. | Damage slight in specially designed structures; considerable in ordinary, substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Destruction of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected from ground in small amounts. Changes in well water. Persons driving motor cars disturbed. |
| IX. | Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. |
| X. | Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Ground badly cracked. Rails bent. Considerable amount of landslides from river banks and steep slopes. Shifted sand and mud. Water splashed over banks. |
| XI. | Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly. |
| XII. | Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown upward into the air. |

There are other scales designed to measure the strength of earthquakes, but the Richter and the Modified Mercalli are the most common and widely used methods.

## Historical Occurrence and Response

Although accounts of the explorers, Lewis and Clark hearing distant loud, rumbling sounds in the Great Falls area in 1805, have often been used as evidence of early earthquake activity in Montana, the first known earthquake in Montana was reported by D. S. Tuttle in 1869, in Helena. The intensity of this quake was such that houses shook causing overturned furniture and broken dishes. As can be seen in Table 3, a number of principal quakes have been recorded since then that exceeded a magnitude of 5 (Qamar and Stickney, 1983). Although one significant earthquake has occurred in Eastern Montana (1909), the majority have occurred in a northwest-trending zone from Yellowstone National Park through Three Forks, Helena and Kalispell (See Figure 2).

Figure 3 shows a summary of the maximum Modified Mercalli intensity experienced at sites in Montana from all historical earthquakes from 1925 to 1977.

Eleven seismic regions have been delineated in Montana based on unique patterns of seismicity or active faults (See Figure 4). A brief earthquake history of each region follows:

**TABLE 3: Principal earthquakes in Montana, 1869 - 1986.** Felt areas and magnitudes in parentheses are estimated by authors (Qamar and Stickney, 1986 and Stickney, 1986).

| Date dy/mo/yr | Location (Hour and minute in parentheses) | Felt area (thousands of km²) | Intensity | Magnitude |
|---|---|---|---|---|
| 10/12/1872 | Deer Lodge | (30) | VII | (5.0) |
| 06/09/1895 | Butte | (30) | | (5.0) |
| 05/06/1897 | South of Helena | (30) | | (5.0) |
| 04/11/1897 | Dillon | (500) | VI? | (6.4) |
| 15/05/1909 | Eastern Montana | 1300 | VI? | 6.5 |
| 19/04/1910 | Butte | (70) | | 5.4 |
| 27/06/1925 | Clarkston | 803 | VIII | 6.75 |
| 10/08/1925 | Sweet Grass | 65 | V | (5.3) |
| 12/12/1926 | Three Forks | 78 | V | (5.4) |
| 15/02/1929 | Lombard | 104 | V | (5.6) |
| 12/10/1935 | Helena | 181 | VII | (5.9) |
| 18/10/1935 | Helena | 596 | VIII | 6.3 |
| 31/10/1935 | Helena | 363 | VIII | 6.0 |
| 28/11/1935 | Helena | 233 | VI | (6.0) |
| 23/09/1945 | Flathead Lake | 93 | VI | (5.5) |
| 23/11/1947 | Virginia City | 388 | VIII | 6.3 |
| 31/03/1952 | Big Fork | 91 | VII | (5.5) |
| 17/08/1959 | Hebgen Lake | 1554 | X | 7.1 |
| 18/08/1959 | Hebgen Lake (00:56) | | | 6.5 |
| 18/08/1959 | Hebgen Lake (01:41) | | VI | 6.0 |
| 18/08/1959 | Hebgen Lake (04:03) | | | 5.6 |
| 18/08/1959 | Hebgen Lake (08:26) | | | 6.5 |
| 18/08/1959 | Hebgen Lake (21:04) | | V | 6.0 |
| 19/08/1959 | Hebgen Lake | | V | 5.0 |
| 21/10/1964 | Hebgen Lake | 65 | V | 5.8 |
| 05/01/1965 | Dillon | 31 | VI | 5.1 |
| 01/07/1974 | Hebgen Lake | | | 5.1 |
| 03/02/1975 | East of Kalispell | 50 | VI | 5.0 |
| 11/03/1977 | Hebgen Lake | | IV | 5.2 |

**Flathead Lake**

Flathead Lake seismicity is characterized by earthquake swarms, not single events. Significant swarms occurred in the area in 1945, 1952, 1964, 1969, 1971 and 1975 (Qamar, et al., 1982). Earthquakes in the Flathead Valley indicate that faults are currently active in the region. The highest activity is on the west side of the lake (Stevenson, 1976). Despite the high activity, magnitude 5.5 earthquakes are the largest ever recorded in the region.

**Helena-Ovando**

This region consists of the Helena, Avon and Ovando Valleys, with Helena having the most seismic activity. Two major earthquake swarms, have occurred in this region; one in 1935 included earthquakes of 6.25 and 6.0 magnitude. Another, smaller swarm occurred in Helena in 1945. The amount of activity has decreased since the mid-1950's (Freidline, et al., 1976). Some activity in the Avon Valley is attributable to a northwest trending normal fault that forms the northeast edge of the valley (Stickney, 1978). Several active faults lie within this region (Stickney, 1983).

**Butte**

A few tremors have been recorded in the Butte area, but there is no record of felt earthquakes by citizens throughout Butte's history. The Continental Fault, a high-angle normal fault, trending north-south is probably responsible for the seismicity (Reilinger, et al., 1977). Since any activity during historic times has been slight, damaging earthquakes are unlikely in the Butte area.

**Three Forks**

The Clarkston and Townsend Valleys as well as the Three Forks Basin are included in this region. On June 27, 1925, a 6.75 magnitude event struck the Clarkston Valley and a strong shock in 1952 was centered in the Townsend Valley. About 70 percent of the recorded earthquakes have occurred since 1960, but this increase may be due to incompleteness of the National Oceanic and Atmospheric Administration

**Figure 3.** Maximum observed earthquake intensities (Modified Mercalli Scale) for Montana during the period from 1925 to 1977. Arabic numerals used for clarity. (from Qamar and Stickney, 1983).

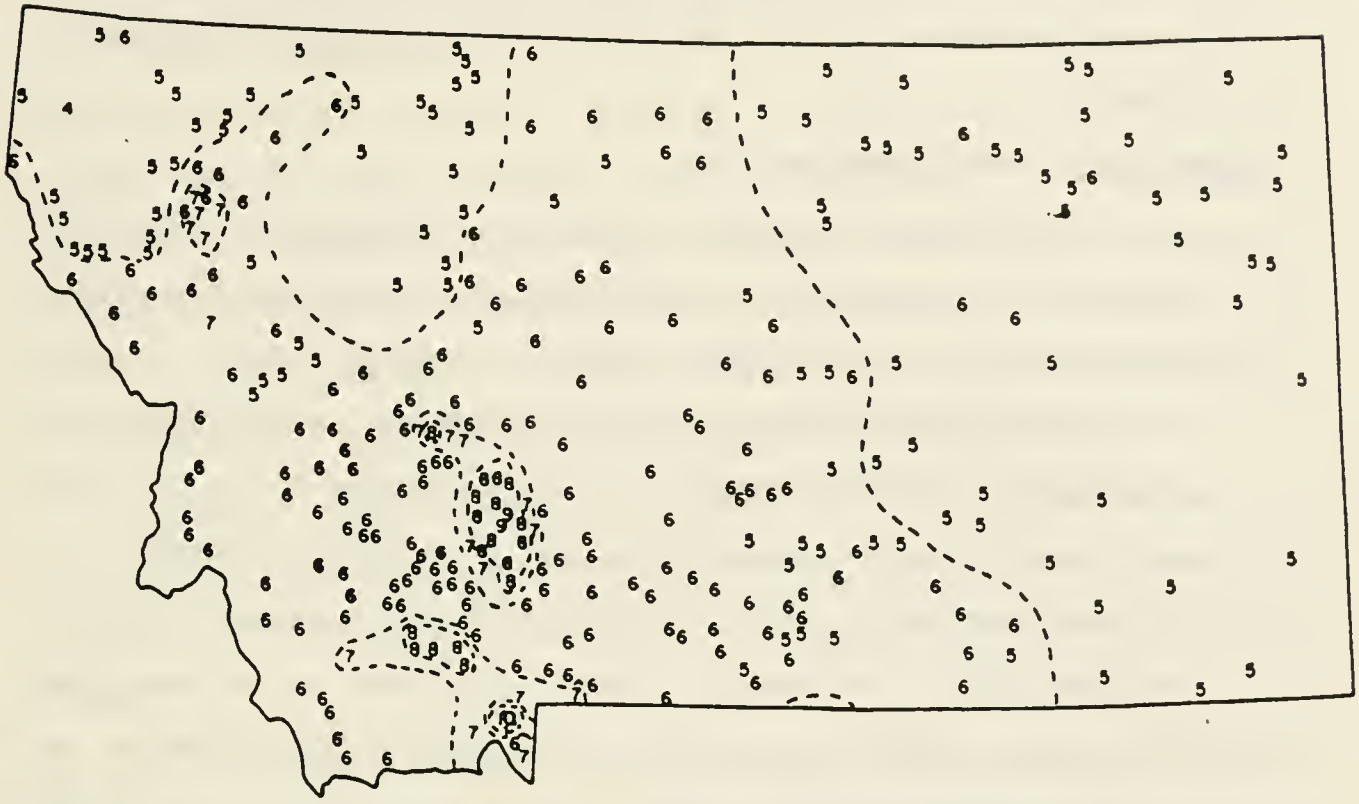
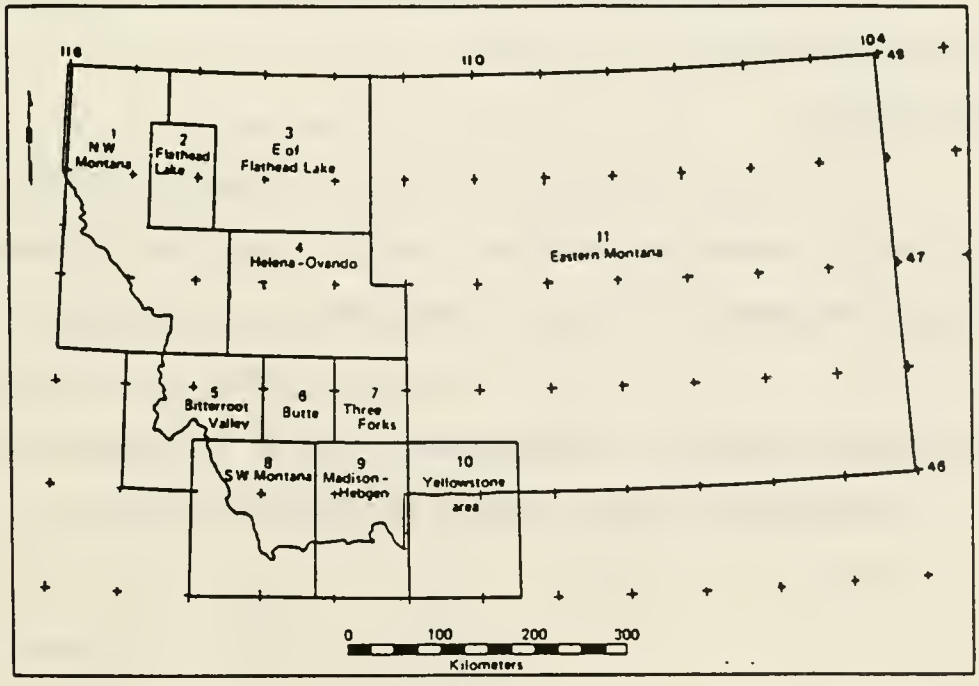


**Figure 4.** Index map of the 11 seismic regions in Montana. (Qamar and Stickney, 1983).



data (Qamar and Hawley, 1979). The most seismically active areas within the Three Forks Basin are near Amsterdam and Manhattan and the southwestern part of the basin near Willow Creek (Qamar and Hawley, 1979).

**Madison-Hebgen and Yellowstone Area**

The Madison Valley, Hebgen Lake and Yellowstone Park region is very active seismically, experiencing five earthquakes greater than magnitude 6 in 1947 and 1959 (Qamar and Stickney, 1983). The well known Hebgen Lake Earthquake of August, 1959 was the largest recorded earthquake in Montana, measuring 7.1 on the Richter scale. This event took the lives of 28 people and caused over $11,000,000 in damage (Trimble and Smith, 1975). In 1964, a 5.8 magnitude event struck the Madison Valley. Seismicity in the region shows an east-west trend with most activity occurring on the northern shore of Hebgen Lake (Gary, 1980). The tremors occur in a zone that is 12 miles in width on the western edge, but widens eastward as it nears the Yellowstone Caldera (Smith et al., 1977).

**Other Regions**

Other areas of Montana register little or no seismic activity and can be considered relatively safe from earthquake hazard. A single, isolated shock of about 6.5 magnitude was felt in Eastern Montana in 1909, but the epicenter location is unknown. Some researchers have placed the source in Saskatchewan, Canada, but it most likely occurred in northeastern Montana (Qamar and Stickney, 1983).

## PREDICTION POTENTIAL FOR RECURRENCE

Many researchers have unsuccessfully tried to forecast earthquake occurrence. Even guessing that an event will occur within six months cannot be done with any degree of accuracy. Predicting the area where an earthquake will happen is an easier, more reliable task. Since earthquakes are usually associated with faulting, any region containing active faults is potentially dangerous. Unfortunately and inexplicably, earthquakes also strike within zones that do not contain faults, and, because the community is unaware of the potential hazard, extensive damage often occurs.

Instead of predicting when an earthquake will strike, an estimate of their likelihood of recurring within a given time frame is given. Qamar and Stickney (1983), using data from Qamar and Breuninger (1979), have concluded that:

1. In all of western Montana an event of magnitude greater than 5 can be expected every 1.5 years, a magnitude 6+ event every 10 years, and a magnitude 7+ event every 77 years.
2. The highest recurrence rate of large earthquakes in Montana occurs in the Hebgen Lake-Yellowstone region, followed by Helena and Three Forks.
3. In the Three Forks and Helena-Ovando regions the return time for a magnitude 6+ event is about 70 years, and that of a magnitude 7+ is 360 to 470 years.
4. The number of large earthquakes in the Flathead Lake region is abnormally small compared to the number of small events. It is not clear whether a major (magnitude 7) earthquake can be expected to occur in that region.

Although earthquake prediction is difficult at best, there are warning signs which can be interpreted to indicate both the place and the time of an impending event. Earthquakes most commonly occur in the same place as prior earthquakes, that is, along active faults. The term "active" is often interpreted by nonscientists as meaning "active during historical time (the last 100 years)." Active faults are most commonly indicated by microseismicity (earthquakes so small that they can only be detected by instruments) and by the presence of scarps. Scarps are steep, linear slopes, up to 65 feet high, showing offset of the ground surface. They are commonly found along the base of mountain ranges, and are prominent in the Madison and Yellowstone (Paradise) Valleys. Interestingly, neither of these valleys has recorded an earthquake in historical times.

As the stress builds, an impending earthquake may be signalled by precursors: phenomena which occur in a characteristic way prior to an earthquake. Precursors include an increase in microseismicity, which has been credited with causing unusual animal behavior. Dogs have howled and cattle left an area hours before an earthquake. Instruments, however, may be more reliable. The velocities of seismic waves through stressed rocks may decrease immediately prior to an event. Well water quality may change, as well as spring discharge. The ground surface may also be slightly deformed. "Earthquake lightning" has been observed just prior to an earthquake, and is believed to be due to the development of an electrical charge on stressed quartz grains (Costa and Baker, 1981).

All of these phenomena may occur prior to a major earthquake, yet be unobserved or unrecognized due to the lack of a monitoring system. Unlike volcanos, where only about 25 sites nationwide require monitoring,

earthquakes may occur at thousands of localities. Because of the cost of monitoring facilities, it is unlikely that such warning signs will be observed outside of major population centers (such as southern California) and university cities.

## STATE VULNERABILITY TO EARTHQUAKE

The entire State of Montana is to some extent vulnerable to the effects of an earthquake. Numerous factors contribute to determining an areas' vulnerability: historical occurrence and proximity to faults; soil characteristics; building construction; and, population density, to mention only a few.

Based on the observed maximum Modified Mercalli intensities for Montana (Figure 3) and the distribution of known active faults, a map of predicted Maximum Mercalli intensities has been generated (Figure 5). This map includes areas of water-saturated alluvium (from Montagne and others, 1982), where intensities would be increased. In its designation of high-risk areas, this map is conservative, as it does not include areas such as the Bitterroot and Paradise Valleys, where fault-related topography is present, yet there is no record of historical macro- or micro-seismicity.

By combining this earthquake hazard map with the population density overlay (back pocket of binder), a composite map is produced which gives some indication of levels of susceptibility to earthquake effects across the state. As can be seen from this map, the southwest portion of the state is the most susceptible to earthquake activity. Adding consideration of population concentration, Helena and Bozeman should be considered the most vulnerable locations followed by Missoula, Butte and Kalispell. According

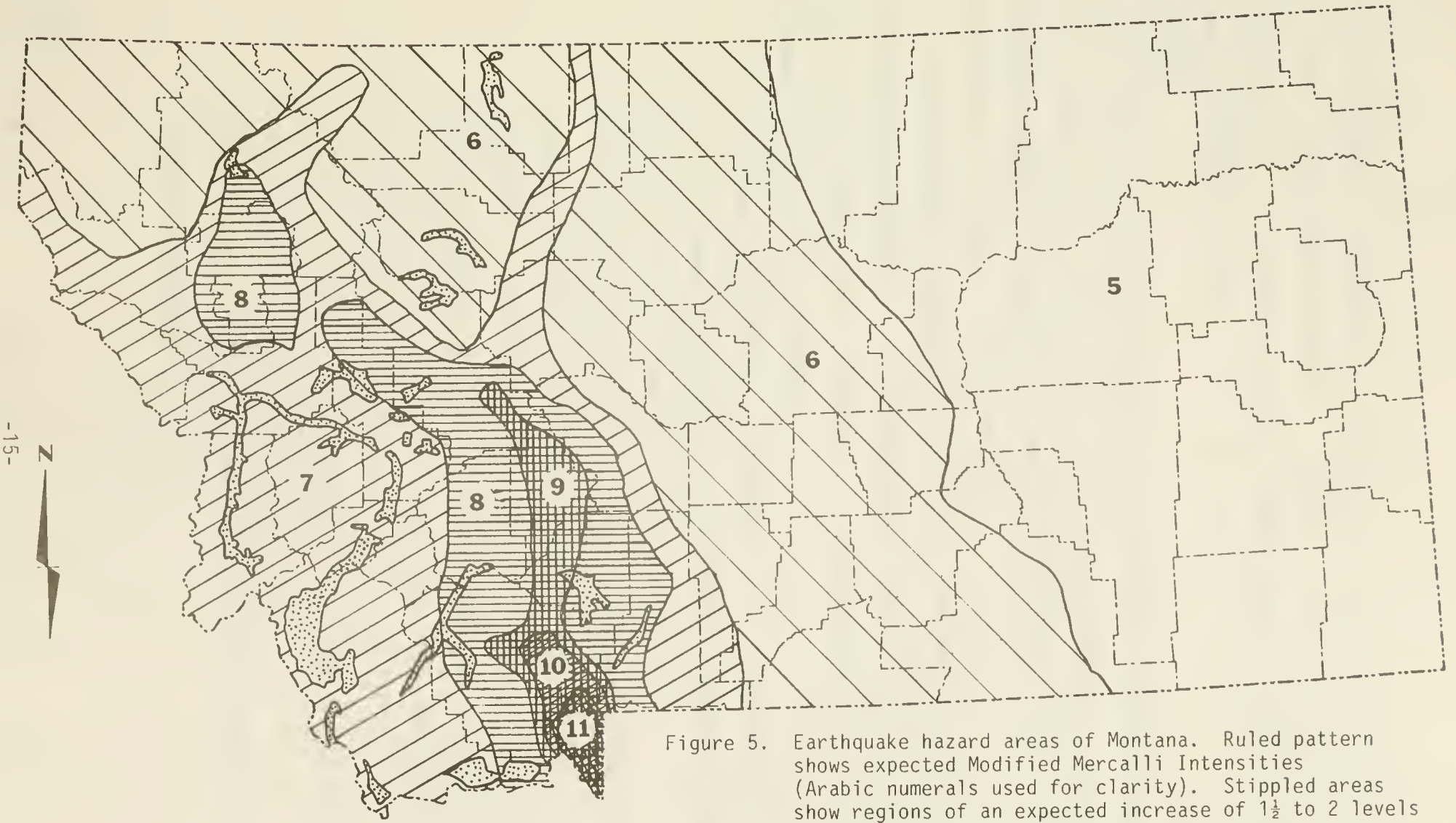



Figure 5. Earthquake hazard areas of Montana. Ruled pattern shows expected Modified Mercalli Intensities (Arabic numerals used for clarity). Stippled areas show regions of an expected increase of 1½ to 2 levels of intensity for that area. (Montagne et al, 1982, MSU Earth Sciences Department, 1985, and Qamar and Stickney, 1983.)

to the 1980 Census, the population of these five cities alone is 128,477, over 16% of the State's populace. Seasonal tourism increases the vulnerability in all areas, but the increase would be greatest in the Yellowstone-Hebgen Lake area.

**MITIGATION**

By assessing earthquake potential, the necessary precautions can be taken to avoid major tragedy and loss of life in Montana. Twenty-one seismograph stations are presently in operation in Montana. Table 4 lists the operators and locations of these stations.

Data from these sources add significantly to knowledge in the field of earthquake hazard mitigation. This knowledge can be applied in planning to mitigate the effects of an earthquake. There are many areas in which earthquake mitigation may be advanced:

- Earthquake risk zones should be mapped at a scale which allows local government decision-makers to implement defensible land-use planning, zoning and subdivision regulations.
- The seismic monitoring network should be expanded to include counties considered to have significant earthquake risk.
- Regulations are needed which require that critical public buildings (schools, hospitals, nursing homes, etc.) in earthquake prone areas, be constructed such that they exceed existing uniform building code standards.
- Research is needed in the development of reliable warning systems for associated hazards (e.g., dam failure).
- Pre-event recovery planning and exercising which coordinates all responding agencies is critical.

- As is the case with all potential hazards, public education is essential to effective mitigation. The public should be made aware of earthquake probability and effects as well as suggested protective measures for themselves and their property.

**Table 4.** Operators and Locations of Seismography Stations in Montana (Stickney, 1986)

EARTHQUAKE STUDIES OFFICE (ESO), MONTANA BUREAU OF MINES & GEOLOGY

Butte
Limekiln Ridge
Lewis & Clark Caverns
Sixmile Mountain
York Bridge
Reservoir Flats
Summit Valley
East Ridge
Delmo Park

AMATEUR OPERATED STATION

Helena

UNIVERSITY OF MONTANA

Missoula
Nine Mile Creek

U.S. ARMY CORPS OF ENGINEERS

Libby Dam
Rexford
Yaak
Calx Mountaain
Little Hoodoo Mountain

UNIVERSITY OF UTAH/U.S. GEOLOGICAL SURVEY/NATIONAL PARK SERVICE

Denny Creek
West Yellowstone
Maple Creek

U.S. FOREST SERVICE

Quake Lake

## SUMMARY

Montana has experienced many major earthquakes in the past; there is every reason to believe that similar events will occur in the future. Future earthquakes will, in general, occur where they have been recorded or where evidence is preserved of their prehistoric occurrence. Western Montana is more susceptible to a large earthquake than the eastern part of the state, however, a significant seismic event in eastern Montana is possible. Western Montana, the Yellowstone-Hebgen and Three Forks-Helena areas are most likely to suffer a damaging earthquake.

Damage from earthquakes includes the direct and indirect effects of ground breaking and ground shaking. The former are confined to fault zones, and can be reduced by mapping of fault zones and mandating their open-space use. Ground shaking and attendant hazards can be minimized by recognition of geological factors which may amplify shaking (primarily the presence of thick, unconsolidated, water-saturated sediment), and by design and construction of earthquake-resistant structures. The implementation of these mitigative actions requires education of the people and their government as to the risks and the alternatives.

## REFERENCES


American National Standards Institute (ANSI), 1982, American National Standard minimum design loads for buildings and other structures: ANSI A58.1 - 1982.

Ayre, R. S., Mileti, D. S., and Trainer, P. B., 1975, Earthquake and tsunami hazards in the United States: A research assessment. Monograph #NSF-RA-E-75-005, University of Colorado, 109 p.

Ballard, J. H., 1975, Strong-motion accelerograms of Montana earthquakes; Northwest Geology, v.8, pp. 69-75.

Becker, B. (ed.), 1986, New gauge could provide warnings about earthquakes: Emergency Preparedness News, Vol. 10, No. 6, March 24, 1986.

Bolt, B.A., Horn, W.L., MacDonald, G.A., and Scott, R.F., 1975, Geological Hazards: Springer-Verlag, New York; pp. 328.

Clement, W.P., 1985, Earthquake hazard in Montana: Unpublished report, Geology Department, University of Montana, Missoula, MT, p. 16.

Committee on Seismology, 1969, Seismology - Responsibilities and requirements of a growing science. Part II - Problems and aspects: Division of the Earth Sciences National Research Council, National Academy of Science.

Code of Federal Regulations, 1978, Title 10, Energy: Part 100 (10 CFR 100), Reactor site criteria; Appendix A, seismic and geologic siting criteria for nuclear power plants: United States Nuclear Regulatory Commission, Washington D.C.

Costa, J. E. and Baker, V. R., 1981, Surficial geology - Building with the earth. John Wiley and Sons, New York, pp. 56-96.

DeNevi, D., 1977, Earthquakes. Celestial Arts, 225 p.

Esp, D. and Metesh, J., 1985, An evaluation of the potential hazard of earthquakes in Montana: Unpublished report, Department of Earth Sciences, Montana State University, Bozeman, MT, p. 14.

Friedline, R.A., Smith, R.B.,, and Blackwill, D.D., 1976, Seismicity and contemporary tectonics of the Helena, Montana area: Bulletin of the Seismological Society of America, v. 66, pp. 81-95.

Gary, S.D., 1980, Quaternary geological and geophysics of the upper Madison Valley, Madison County, Montana: M.S. Thesis, University of Montana, Missoula, MT, pp. 76.

## REFERENCES - Con't


Montagne, C., Munn, L.D., Nielsen, G.A., Rogers, J.W. and Hunter, H.E., 1982, Soils of Montana: MT Agricultural Experiment Station Bull. No. 744, Montana State University, Bozeman, MT, p. 95.

Montana Civil Defense Division, 1976, Hazard/vulnerability analysis. MT Disaster Preparedness Program, pp. 14-33.

Qamar, A. and Breuninger, R., 1979, Earthquake hazard to the proposed Northern Tier Pipeline in Montana: in Northern Tier Pipeline Report No. 4, Montana Department of Natural Resources and Conservation: Helena, pp. 54.

Qamar, A. and Hawley, B., 1979, Seismic activity near the Three Forks Basin, Montana: Bulletin of the Seismological Society of America, v. 69, pp. 1917-1929.

Qamar, A., Kogan, J. and Stickney, M.C., 1982, Tectonics and recent seismicity near Flathead Lake, Montana: Bulletin of the Seismological Society of America, v. 72, pp. 1591-1599.

Qamar, A. and Stickney, M.C., 1983, Montana earthquakes, 1869-1979: Montana Bureau of Mines and Geology, Memoir 51, pp. 79.

Reilinger, R.E., Citron, G.P.and Brown, L.D., 1977, Recent vertical crustal movements from precise leveling data in southwestern, Montana, western Yellowstone National Park, and the Snake River Plain: Journal of Geophysical Research, v. 82, p. 5349-5359.

Sbar, M., Barazangi, M., Forman, J., Scholz, C.H. and Smith, R.B., 1972, Tectonics of the Intermountain Seismic Belt, western United States: Microearthquake seismicity and composite fault plane solutions: Geological Society of American Bulletin, v. 83, pp. 13-28.

Schnabel, P.B. and Seed, H. B., 1973, Acceleration in rock for earthquakes in the western United States: Bulletin of the Seismological Society of America, v. 63, pp. 501-516.

Smith, R.B., Shuey, R.T., Pelton, J.R. and Bailey, J.P., 1977, Yellowstone Hot Spot: Contemporary tectonics and crustal properties from earthquake and areomagnetic data: Journal of Geophysical Research, v. 82, pp. 3665-3676.

Stevenson, P.R., 1976, Microearthquakes at Flathead Lake, Montana; A study using automatic earthquake processing: Bulletin of the Seismological Society of America, v. 66, pp. 61-80.

Stickney, M.C., 1978, Seismicity and faulting of central western Montana: Northwest Geology, v. 7, pp. 1-9.

## REFERENCES - Con't


Stickney, M.C., 1980, Seismicity and gravity studies of faulting in the Kalispell Valley, Northwest Montana: M. S. Thesis, University of Montana, Missoula, MT, pp. 82.

Stickney, M.C., 1985, Montana map - epicenters of earthquakes with magnitudes of 3.0 or greater: Bureau of Mines and Geology, a department of Montana College of Mineral Science and Technology, Butte, MT.

Stickney, M.C., 1986, Montana Seismicity 1984: Montana Bureau of Mines and Geology, a department of Montana College of Mineral Science and Technology, Butte, MT, p. 305.

Stickney, M.C., Director, Earthquake Studies Office, Montana Bureau of Mines and Geology, 1986, Personal communication.

Trimble, A.R. and Smith, R.B., 1975, Seismicity and contemporary tectonics of the Hebgen Lake-Yellowstone Park region: Journal of Geophysical Research, v. 80, pp. 733-741.

Witkind, I.J., 1972a, Earthquake hazard map of the Henry's Lake Quadrangle, Idaho and Montana: United States Geological Survey Map I-781E.

Working Group on Earthquake Hazards Reduction, 1978, Earthquake hazards reduction - Issues for an implementation plan: Office of Science and Technology Policy, Office of the President, Washington, D.C. 169 p.

# VOLCANIC ERUPTION[1]

There may be no natural event that can cause greater damage to its surrounding area than the eruption of a volcano. However, eruptions can be mild, almost passive events that have little effect outside their immediate surroundings. The range of destructive capability is a function of the type of volcanic activity. Montana is bordered on two sides by areas of volcanic activity. To the west are the volcanos of the Cascade range (Mt. St. Helens, Mt. Rainier, Mt Hood, etc.), and to the south is the Yellowstone Caldera.

The degree of destructiveness of a volcanic eruption is dependent on many factors. The frequency, magnitude, and duration of the eruptions, the nature of ejected material, the preexisting topography, and the weather conditions interact with such variability that a precise assessment of potential hazard is impossible. However, the risks associated with each type of eruption can be discussed.

There are two major types of volcanos, shield volcanos and composite volcanos. Shield volcanos are found in the ocean and are typical of those in the Hawaiian Islands. Composite volcanos are found on the continents and are typical of those in the Cascades. They are very explosive and often send huge clouds of ash and other volcanic debris far up into the atmosphere. These ash clouds can cover large areas and can even drop



---

[1] Based principally on data provided by Bradford R. Burton and Vern Heisler, graduate students, Dept. of Earth Sciences, Montana State University, and Kevin-Paul Craig Vang, graduate student, Geology Department, University of Montana.

several inches of ash thousands of miles from the volcano. The damage caused by these volcanos is extensive and widespread. It is this type of volcano that affects Montana.

Composite or explosive eruptions not only produce large amounts of ash, but also pyroclastic flows (rock and mineral fragments blown out of a volcanic vent during an eruption) and mudflows on and beyond the flanks of the volcano.

The distribution of ash from a violent eruption is a function of the weather, particularly wind direction and velocity, and the duration of the eruption. As the prevailing wind in the mid-latitudes of the northern hemisphere is generally from the west, ash is usually spread eastward from the volcano. Exceptions to this rule do, however, occur. Ash fall, because of its potential widespread distribution, offers some significant volcanic hazards (Table 1).

**Table 1.** Hazardous effects of ash fall (Warrick, 1975).

| Affected | Immediate | Latent |
|---|---|---|
| Health | Suffocation<br>Blocked water supplies | Respiratory disease<br>Contaminated water |
| Structures | Collapse | Corrosion |
| Transportation | Roads closed<br>Airports closed<br>Visibility reduced | Equipment damaged |
| Agriculture | Suffocation of low plants & grasses<br>Suffocation of Livestock<br>Loading damage to trees | Respiratory disease<br>Digestive disorders |
| Climate | Changes in snowmelt | Lowered temperature<br>Increased precipitation |

Lateral blasts, hot fragments and gases ejected laterally at high speed from explosive volcanos, endanger people primarily because of their heat, rock fragments carried, and high speed which may not allow sufficient escape time.

Pyroclastic flows consist of masses of hot dry rock debris that move like a fluid. The fluid nature is caused by hot air and other gases which mix with the debris. Pyroclastic flows form when large masses of hot rock fragments are suddenly erupted onto the flanks of a volcano. These flows can move downslope at speeds of as much as 100 miles per hour. Principle losses are caused by the swiftly moving flow of hot rock debris, which could bury and incinerate everything in its path. The accompanying cloud of hot dust and gases, which would extend beyond the flow could cause asphyxiation and burning of the lungs and skin.

Mudflows consist of water-saturated rock debris commonly derived from loose unstable rock deposited by explosive eruptions. The added water which initiates the flow may be provided by rain, melting snow, a crater lake, or a lake or reservoir adjacent to the volcano. Mudflows may also be generated by a pyroclastic flow or a lava flow that has moved across snow and melted it. This phenomenon may travel as far as 60 miles from the source. The greatest threat to man from a mudflow is burial. Structures may also be buried or transported by the flow.

Lava flows usually appear hours, days or weeks after the original eruption. Because they move very slowly, these flows present no direct danger to humans. They do, however, usually destroy everything in their path (Hays (ed), 1981).

In addition to the hazards already discussed, volcanic eruptions can also induce earthquakes, floods, landslides and fires.

## HISTORICAL OCCURRENCE AND RESPONSE

Although there are no active volcanos in Montana at present, there have been several eruptions in the recent geologic past. Between 70 and 100 million years ago southcentral and southwestern Montana had extensive volcanic activity in association with the emplacement of a large mass of molten rock known today as the Boulder Batholith, and between 30 and 60 million years ago the Bear Paw and Absaroka Mountain regions along with several other areas in westcentral and southwestern Montana also experienced numerous eruptions (see Figure 1). There are many well exposed remnants of this latest volcanic activity in several Montana counties. Since this time no eruptions have been recorded in the State. However, Montana has experienced numerous ashfalls from volcanos in the Cascade region.

The Cascade Range includes 15 major volcanos, of which six (Mt. Baker, Mt. Rainier, Mt Hood, Mt Shasta, Lassen Peak, and Mt. St. Helens) are considered active, three (Glacier Peak, Mt. Adams, and Newberry Volcano) are considered dormant, and the remaining six (Mt. Garibaldi, Mt. Jefferson, the Three Sisters, and Mt. Mazama [Crater Lake]) are considered extinct (Hyde and others, 1978). The only plausible threat these volcanos pose to Montana is that of ash fall. The likely extent of such ash fall can be estimated on the basis of past eruptions.

**Glacier Peak.** The last major eruption of Glacier Peak (about 11,200 years ago) resulted in the deposition of ash across southwestern Montana (Figure 2). Compacted ash thicknesses exceed 2-1/2 inches (6 cm) throughout much of this region.

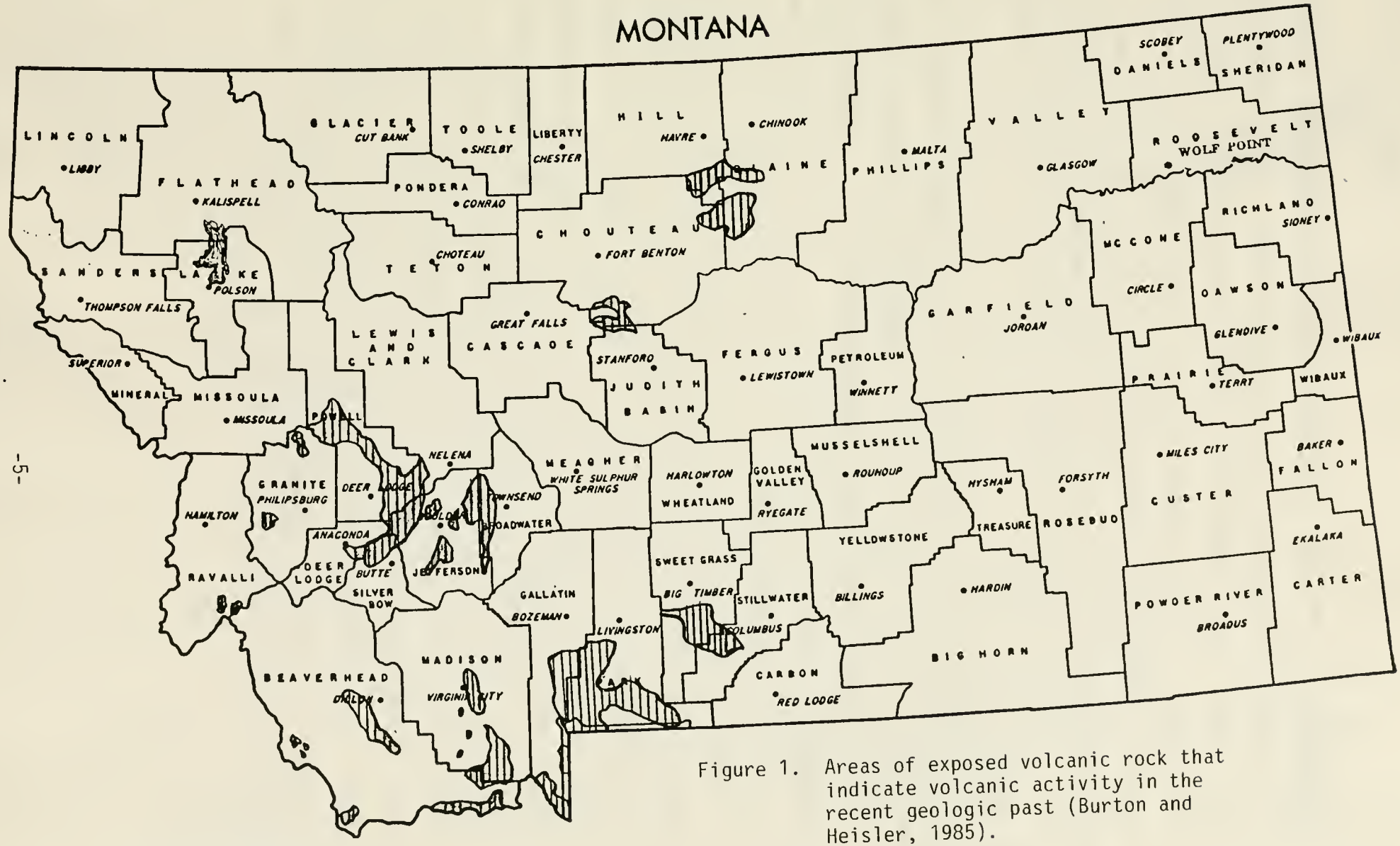



Figure 1. Areas of exposed volcanic rock that indicate volcanic activity in the recent geologic past (Burton and Heisler, 1985).

No. 1052 — County Outline Map
STATE PUBLISHING COMPANY
Helena

**Mount Mazama.** The eruption of Mt. Mazama (about 6,600 years ago) was one of the most spectacular eruptions known from the Cascades. About 97,000 cubic yards (75 cubic km) of material was ejected, leaving behind the scenic basin of Crater Lake. The ash blanket from Mt. Mazama covered western Montana (Figure 2), and compacted ash thicknesses exceeding 15 inches (40 cm) have been noted west of Augusta, MT. Ash thicknesses between 4 and 8 inches (10-20 cm) have been noted near Great Falls, and the blanket thins eastward (Lemke and others, 1975).

**Mount St. Helens.** The May, 1980 eruption of Mt. St. Helens resulted in the deposition of up to 3 inches (7 cm) of uncompacted ash in western Montana (Figure 2), tapering to near zero in eastern Montana. It is estimated that the ashfall cost Missoula nearly $6 million in cleanup and lost work time. The statewide cost has been estimated at between $15 and $20 million.

Another area of volcanic activity that has affected Montana in the past and could pose a serious threat in the future is the Yellowstone Caldera in northwestern Wyoming and northeastern Idaho just south of the Montana border. A caldera is a term for a large volcanic crater. The Yellowstone Caldera is 45 miles across at its greatest diameter. The eruptive center has migrated along the axis of the present Snake River Plain over the past 10 million years, with periodic eruptions generating massive pyroclastic flows. The last three eruptions, about 2.1, 1.3, and 0.6 million years ago, occurred in the Island Park/Yellowstone region of SW Montana and NW Wyoming. Fortunately for mankind, an eruption comparable in magnitude with those of Yellowstone has not occurred during recorded history (Figure 3).

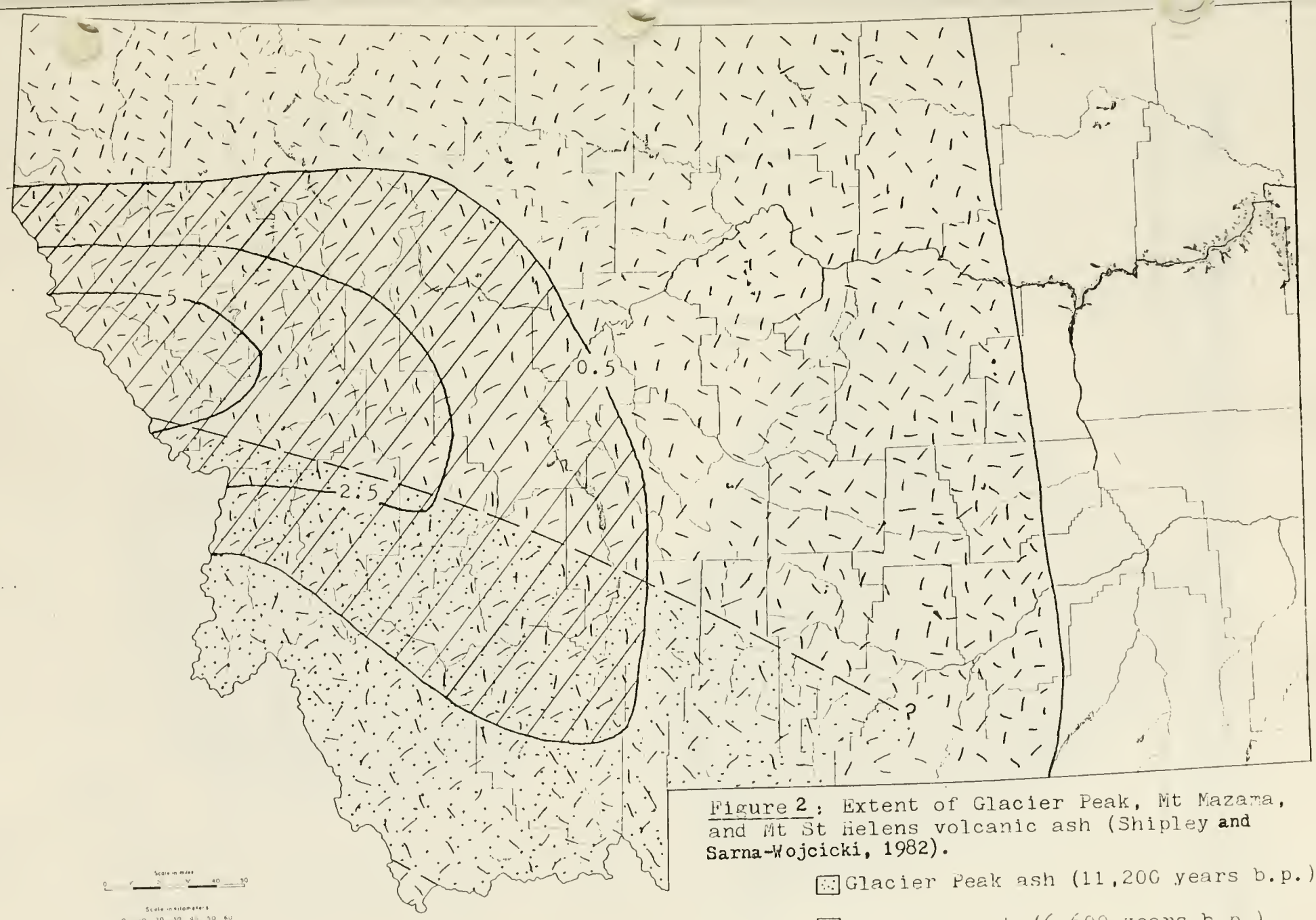


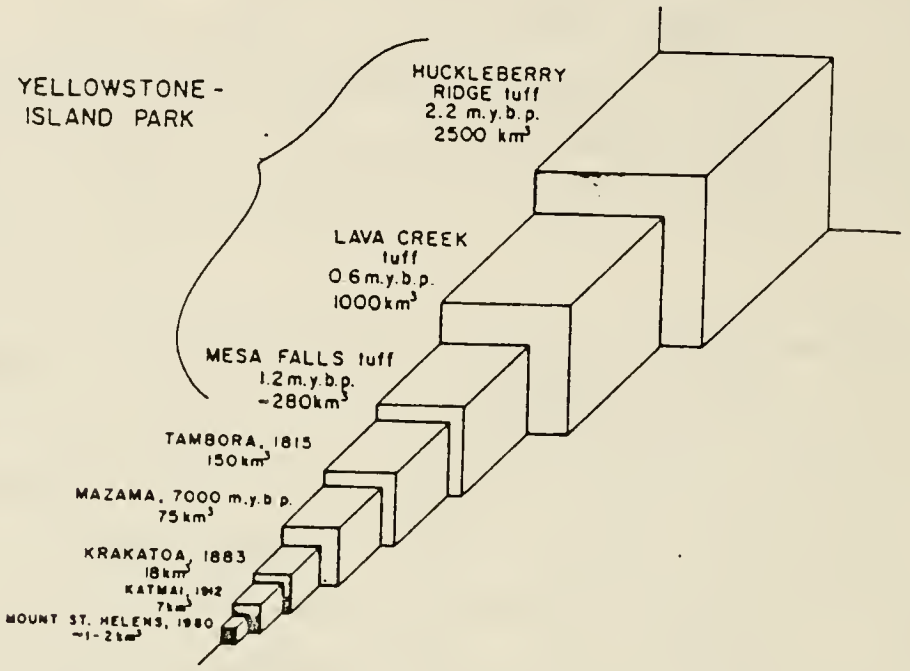

Figure 2: Extent of Glacier Peak, Mt Mazama, and Mt St Helens volcanic ash (Shipley and Sarna-Wojcicki, 1982).

Glacier Peak ash (11,200 years b.p.)

Mt Mazama ash (6,600 years b.p.).

Mt St Helens ash (May 18, 1980).

**Figure 3.** The magnitude of the last three Yellowstone eruptions as compared to historic events (from Smith and Braile, 1984).




The Lava Creek A and Mesa Falls ashes were distributed just south of Montana's borders by a consistent wind from the west or northwest. In contrast, the Lava Creek B and Huckleberry Ridge ashes blanketed much of the Central United States, suggesting fluctuating winds during the eruptive cycle (see Figures 4 and 5). Although the thicknesses of these blankets have not been accurately determined, it is clear that, under certain wind conditions, much of Montana could receive significant ash from a Yellowstone eruption. The hazard of ash fall from a Yellowstone eruption is thus dependent mainly on the weather at the time of the eruption and on the volume of ash produced.

**Figure 4.** Distribution of Lava Creek B Ash (0.62 my), (from Izett and Wilcox, 1982).

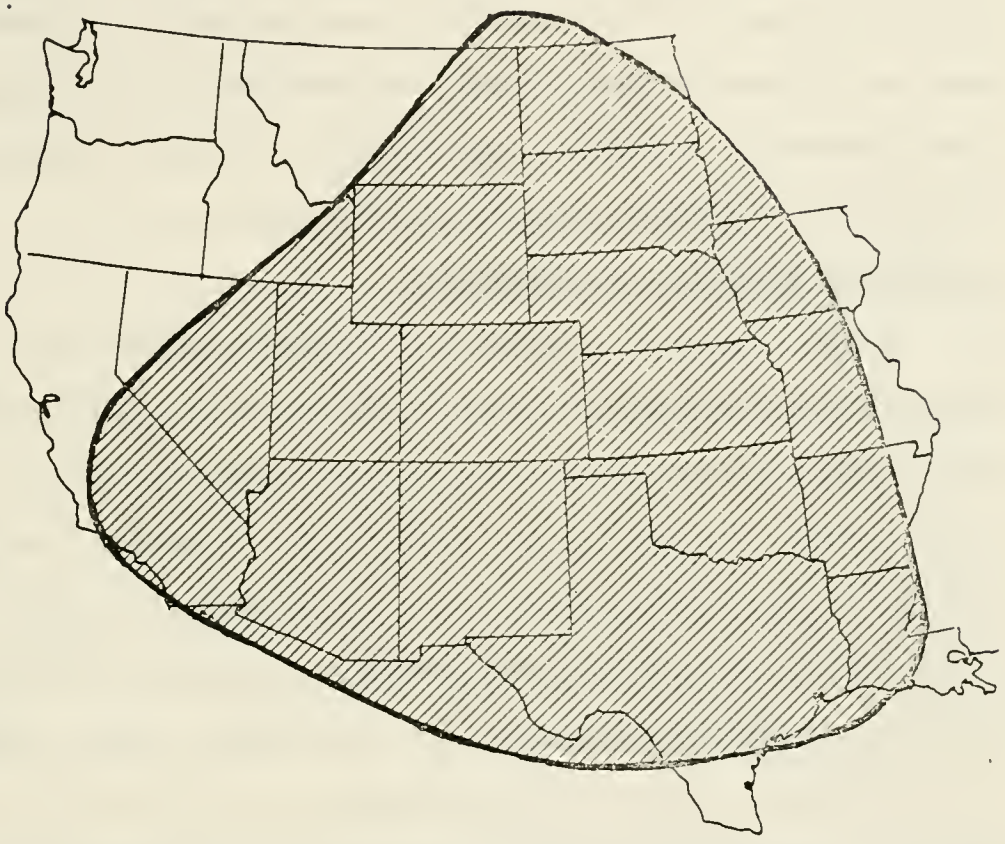
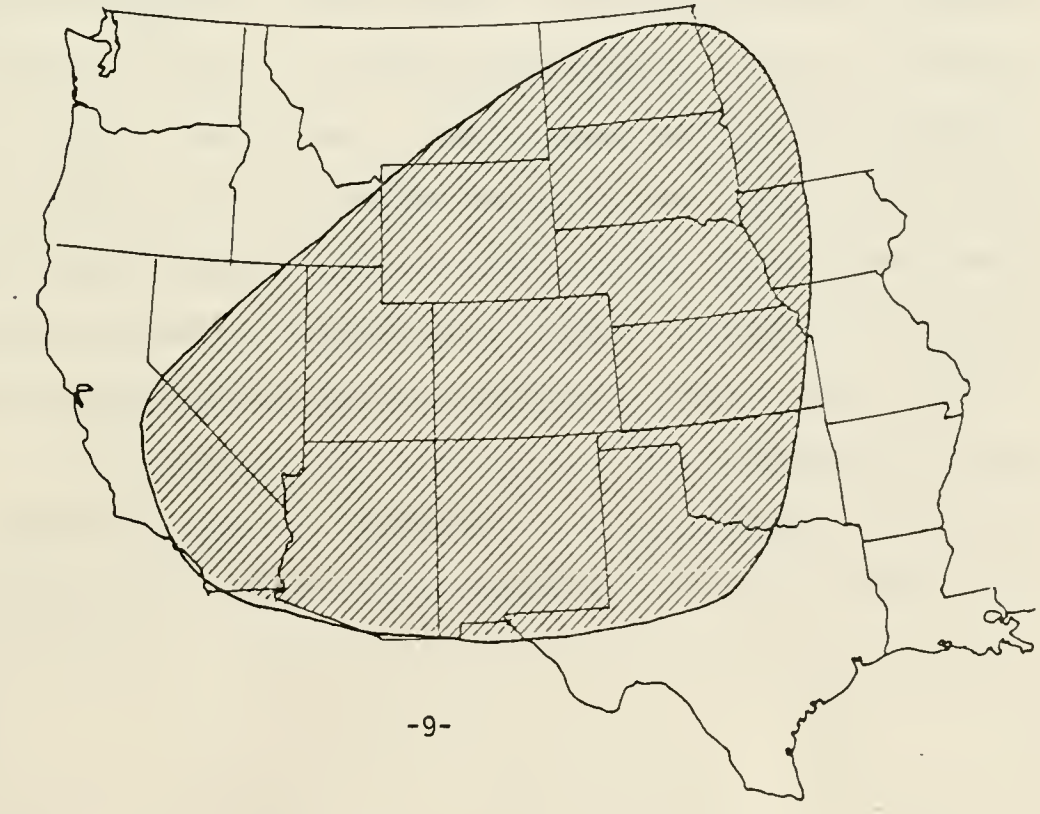


**Figure 5.** Distribution of Huckleberry Ridge Tuff (2.02 my), (from Izett and Wilcox, 1982).



The other primary effects of a volcanic eruption have also been felt within Montana. Initial lava flows were confined to the immediate area of the vent. Later flows affected the headwaters of the Yellowstone River, near Gardiner. In addition, pyroclastic flows (the Huckleberry Ridge Tuff) extended up to 55 miles (90 km) from the vents.

## PREDICTION POTENTIAL FOR RECURRENCE

Given the geological causes of regional volcanism, it is a certainty that further eruptions will occur. The timing of future eruptions, however, is unknown. At present, the only way to assess the probability of eruption of a given volcano is to examine its historical tendencies, and to extrapolate them into the future. This approach assumes that complete record of eruptions is represented in the geologic record, that it has been correctly interpreted by geologists, and that it will continue similarly into the future. None of these assumptions is totally valid. The approach, however, suggests that Cascade volcanos are characterized by periods of dormancy on the order of 10,000 years followed by eruptive cycles with eruptions several hundred years apart. Thus the volcanos currently considered active may erupt at any time, and are likely to erupt if the period since their last eruption exceeds several hundred years. Those considered dormant may also erupt at any time, but have no recent activity by which to judge their near future. Because of the lack of interconnection between magma chambers, the eruption of one volcano apparently has no effect on its neighbors.

The three major periods of activity in the Yellowstone system have occurred at intervals of approximately 600,000 years, and the most recent was about that long ago. The evidence available is not sufficient enough to

confirm that calderas such as the Yellowstone erupt at regular intervals, so the amount of time elapsed is not necessarily a valid indicator of imminent activity. There is no doubt, however, that a large body of molten magma exists, probably less than a mile beneath the surface of Yellowstone Park. The presence of this body has been determined by scientists who note that earthquake waves that pass beneath the park come out the other side lacking precisely the types of wave motion that cannot pass through liquids. The only liquid at that location which could absorb those waves is melted rock. The extremely high temperatures of some of the hot springs in the park provide further evidence of the existence of molten rock at a shallow depth. A small upward movement could easily cause this magma to erupt. If a major eruption occurred, the explosion would be "comparable to what we might expect if a major nuclear arsenal were to explode all at once, in one place" (Alt, 1985).

As with earthquakes, the occurrence of volcanic eruptions is preceded by a number of changes in the geology of the surrounding region. Seismic wave velocities may decrease, implying magma near the surface. Heat flow may increase for the same reason. The frequency of minor earthquakes may increase due to weakening of the heated rocks at depth and to the increase in stresses caused by ascent of magma to the surface. In the case of Mount St. Helens, the depth at which earthquakes occurred decreased as the magma neared the surface (Lipman and Mullineaux, 1981).

All of these warning signs may or may not be present prior to an eruption. It is clear, however, that they will be noticed only if a major program of geophysical monitoring is undertaken.

## STATE VULNERABILITY TO VOLCANIC ERUPTION

Due to the numerous variables involved, it is difficult to assess the vulnerability of the State of Montana to a volcanic eruption. The primary hazard to which the State may be vulnerable at some future time, is ashfall. The effect would depend on the interaction of such variables as source location, frequency, magnitude and duration of eruptions, the nature of the ejected material and the weather conditions. Therefore, the entire state may be considered vulnerable to ashfall to some degree in the event of a volcanic eruption.

Although the probability is minimal, there is the potential for a catastrophic eruption that would devastate Montana. Again, assessing the vulnerability of the State to such an event is impossible due to the numerous variables that must be considered.

## MITIGATION

The infrequency of volcanic eruptions makes zoning to reduce damage inefficient and unworkable. The violence of such eruptions makes engineering to reduce damage nearly impossible. Even if an eruption were to be predicted, the widespread areas affected make evacuation impracticable outside the immediate vent area. As such, the only useful mitigation tactics throughout most of Montana will be those which take place after the eruption. Those techniques will chiefly combat the effects of ash fall.

**Health** In the case of a major Cascade eruption, the major health hazard involves the inhalation of fine glass shards, which may complicate or cause respiratory disorders. Inexpensive filters should be made available to those with existing respiratory disorders and to anyone who must remain

outside, in direct contact with the ash. The ash may clog both storm and sanitary sewers, causing both inconvenience and health hazards. Observation and appropriate maintenance are effective mitigation.

In the case of a Yellowstone eruption, poisonous gasses may be present. The difficulty of filtering such material may require extensive evacuation of areas otherwise little affected by the eruption. Water supplies exposed to such gasses may be contaminated, with long-term damage to local economies. Replacement or filtration will be an expensive, time-consuming task.

**Structures** Most structures in Montana are designed to withstand significant snow loads, so ash loading should not be a major problem. Flat roofs in areas of heavy ash fall, however, may need to be shoveled. Although the density of uncompacted ash is only about 1 gram per cubic centimeter (similar to water), it may increase by 50% when wet (Shipley et al, 1982). The combination of rain and ash fall, therefore, increases the loading by 50%.

**Transportation** The silica-rich glass shards of ash are harder than steel, thus excessive wear of machinery can be expected. The best mitigation for this problem is to use oil bath or foam air filters where possible, rather than paper filters (Schuster, 1981). Air, oil, and gas filters should be changed frequently, as should engine oil. Brake drums will also abrade rapidly, and should be cleaned as often as possible.

When ash is moistened it becomes both an electrical conductor and a corrosive acid. Sensitive equipment and electrical systems should be cleaned as often as possible to prevent short circuits and corrosion.

The removal of ash from highways and airports represented the most widespread problem associated with the 1980 Mt. St. Helens eruption (Schuster, 1981). Plowing was most effective when initiated soon after ash fall began.

**Agriculture** A thin ash blanket is likely to be beneficial to crops, as the ash contains trace minerals often leached from agricultural soil. A thicker blanket will have a similar effect, although it will have to be plowed into the ground, with the loss or sacrifice of any existing crop. Extremely thick ash will require re-vegetation over a period of decades.

Livestock will be subject to the same hazards as humans, and should be provided with filtered air and monitored for respiratory disease as far as possible.

**Climate** Most climatic changes resulting from the addition of particulate matter and aerosols to the atmosphere will be subtle, and will require no mitigation. One possible short-term effect is a change in the rate of snowmelt. A thin ash layer (3 mm; Driedger, 1981) will increase the rate of snowmelt by increasing the amount of solar radiation absorbed at the snow surface. This could slightly increase the possibility of spring flooding, and decrease the storage for summer irrigation. A thick ash blanket will have the opposite effect, acting as insulation at the snow surface.

## SUMMARY

The volcanic hazard is a very unlikely one, yet with such major potential consequences that it should be considered in emergency planning. The most likely hazard to Montana is that of ash fall from an eruption in the Cascades, with the potential of from 0 to 40 inches of ash blanketing

the state. Such eruptions, based on fragmentary records, might occur once a century, on average. Much less likely is the possibility of a catastrophic eruption in the Yellowstone region. Such an eruption might not occur for 100,000 years, but when it does, it will devastate much of SW Montana and neighboring portions of Wyoming. Again, the consequences justify the generation of contingency plans.

The best defense against volcanic hazard is monitoring of potential eruptive centers. The U.S. Geological Survey should be encouraged to continue such monitoring.

## REFERENCE LIST


Alt, D., 1985, Personal communication, University of Montana.

Alt, D., 1985, The Yellowstone volcano - Mankinds loudest bang. in Montana Magazine, November-December 1985, pp. 52-54.

Burton, B.R., and Heisler, V., 1985, An evaluation of the potential hazard of volcanic eruption in Montana: Unpublished report, Earth Sciences Dept., Montana State University, Bozeman, MT. 15 pp.

Christiansen, R.L., 1984, Yellowstone Magmatic evolution: Its bearing on understanding large-volume explosive volcanism. in Explosive Volcanism: Inception, Evolution, and Hazards, National Academy Press, pp. 84-95.

Driedger, C. L., 1981, Effect of ash thickness on snow ablation, in The 1980 eruptions of Mount St. Helens, Washington: United States Geological Survey Professional Paper 1250, pp. 757-759.

Foxworthy, B.L., 1982, Volcanic eruptions of 1980 at Mt. St. Helens: The first 100 days: United States Geological Survey Professional Paper 1249.

Francis, P. 1984, Giant volcanic calderas, Scientific American, June 1984. pp. 60-70.

Hays, W.W. (ed.), 1981, Facing geologic and hydrologic hazards - Earth Science considerations, Geological Survey Professional Paper 1240-B, U.S. Government Printing Office, Washington, D.C. pp.

Izett, G.A., and Wilcox, R.E., 1982, Map showing localities and inferred distribution of the Huckleberry Ridge, Mesa Falls, and Lava Creek Ash Beds (Pearlette Family Ash Beds) of Pliocene and Pleistocene age in the western United States and southern Canada: United States Geological Survey Map I-1325.

Lemke, R.W., Mudge, M.R., Wilcox, R.E., and Powers, H.A., 1975, Geologic setting of the Glacier Peak and Mazama ash bed markers in west central Montana: United States Geological Survey Bulletin 1395-H.

Lipman, P.W. and Mullineau, D.R., 1981, The 1980 eruptions of Mount St. Helens, Washington: United States Geological Survey Professional Paper 1250, 844 pp.

Luedke, R.G. and Smith, R.L., 1984, Potentially active volcanic lineaments and loci in western conterminous United States, in Explosive Volcanism: Inception, Evolution, and Hazards, National Academy Press, pp. 47-66.

## REFERENCE - Con't


Meyer, G., 1985, Holocene vertical surface displacements in Yellowstone National Park: The shorelines of Yellowstone Lake: Unpublished M.S. thesis, Montana State University.

Missoula Missoulian, 1980-1985, Used many issues from early 1980 to present.

Pelton, J.R. and Smith, R.B., 1982, Contemporary vertical surface displacements in Yellowstone National Park: Journal of Geophysical Research, v. 87, pp. 2745-2761.

Schuster, R.L., 1981, Effects of the eruptions on civil works and operation in the Pacific Northwest. in the 1980 eruptions of Mount St. Helens, Washington: United States Geological Survey Professional Paper 1250, pp. 701-731.

Seattle Post Intelligencer 1980-1985, Used many issues from 1980 to present.

Shipley, S. and Sarna-Wojcicki, A.M., 1982, Map showing the Extent of Late Pleistocene and Holocene ash beds in the western United States: United States Geological Survey Map MF-1435.

Smith, R.B. and Braile, L.W., 1984, Crustal structure and evolution of an explosive silicic volcanic system at Yellowstone National Park. in Explosive Volcanism: Inception, Evolution, and Hazards, National Academy Press, pp. 96-109.

Vang, K.P.C., 1985, Volcanic eruption: Unpublished report, Geological Department, University of Montana, Missoula, MT.

Warrick, R.A., 1975, Volcano hazard in the United States: A research assessment. Monograph #NSF-RA-E-75-012, Program on Technology, Environment, and Man: National Science Foundation.

Interviews with several local people in Missoula, Polson, Kalispell, Hamilton, Helena, Butte and Bozeman.


## MAPS


United States base map from **Martin Greenwald Associates, Inc.**

Montana state map from **State Publishing Company.**

# DROUGHT[1]

## DESCRIPTION

Drought must be defined not only in terms of below normal precipitation, but also in terms of duration. Occasional periods of below average precipitation will not seriously deplete moisture reserves, while prolonged shortages of moisture can be enough of a drain on moisture reserves to seriously affect crops, livestock, forest and range lands, as well as hydroelectric, irrigation, and urban water supplies.

The effects of drought become apparent with a longer duration because more and more moisture related activities are affected. Nonirrigated croplands are most susceptible to moisture shortages. Rangeland and irrigated agricultural lands do not feel the effects as quickly as the nonirrigated cultivated acreage, but their yields can also be greatly reduced due to drought. Reductions in yields due to moisture shortages are often aggravated by wind induced soil erosion.

In periods of severe drought, forest and range fires can destroy the economic potential of the timber and livestock industries, and wildlife habitat in, and adjacent to, the fire areas. Under extreme drought conditions, lakes, reservoirs, and rivers can be subject to severe water shortages which greatly restrict the use of their water supplies. An additional hazard resulting from drought conditions is insect infestation.



[1] Based principally on data provided by Ginger Schmid, graduate student, Earth Sciences Department, Montana State University.

The Palmer Drought Severity Index (PDSI), first developed in 1965, is a means of quantifying drought in terms of moisture demands versus moisture supply. Moisture demands include plant requirements and water needed for recharge of soil moisture supplies. An allowance is also included for runoff amounts necessary for recharging both ground water and surface water supplies such as rivers, lakes, aquifers and reservoirs. The PDSI balances these moisture demands against the moisture supply available (Karl, 1983).

The PDSI expresses this comparison of moisture demand to moisture supply on a numerical scale that usually ranges from positive six to negative six. Positive values reflect excess moisture supplies while negative values indicate moisture demands in excess of supplies. Table 1 shows how the numerical values are assigned ratings of severity ranging from normal to extreme.

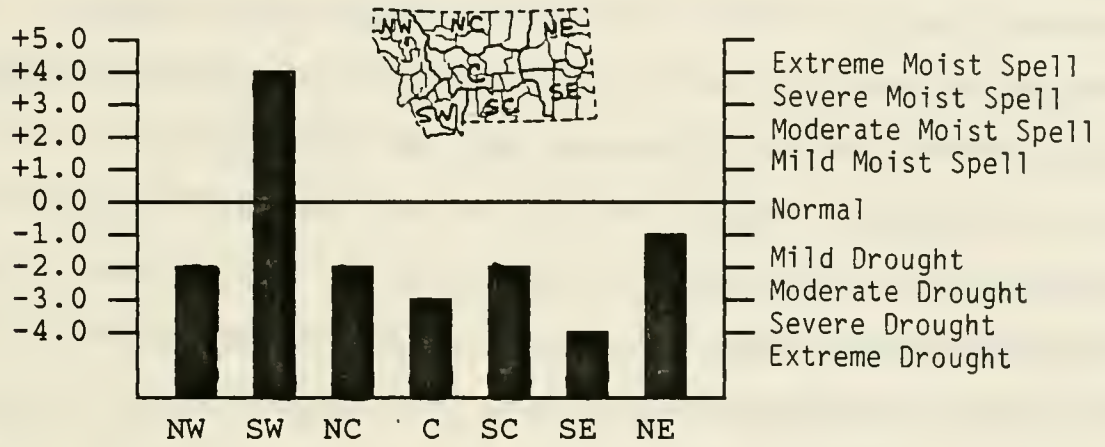
**Table 1.** Palmer Drought Severity Index Ratings (Schmid, 1985).

| RANGE OF PDSI (Absolute Value) | SEVERITY RATING |
|---|---|
| 0.0 - 0.5 | Normal |
| 0.5 - 1.0 | Incipient |
| 1.0 - 2.0 | Mild |
| 2.0 - 3.0 | Moderate |
| 3.0 - 4.0 | Severe |
| Over - 4.0 | Extreme |

The Joint Agricultural Weather Facility, operated by the National Oceanic and Atmospheric Administration and the United States Department of Agriculture (USDA), calculates the PDSI in the United States. Although originally designed to be used on a monthly basis, the PDSI can be calculated more often to reflect relatively rapid changes in moisture

supplies. Currently, the PDSI figures are published twice monthly in the USDA's Weekly Weather and Crop Bulletin. Both the numerical value and the severity rating are mapped on a region-by-region basis for each state. Figure 1 shows a regional breakdown of Montana's PDSI for April 20, 1985.

**Figure 1.** Regional Breakdown of Montana's PDSI for April 20, 1985:




## HISTORICAL OCCURRENCE AND RESPONSE

The 1930's Dust Bowl remains the most highly publicized of past droughts in Montana, but a brief survey of the last 30 years of drought related articles in the Great Falls Tribune shows that the "Dirty Thirties" were by no means the last, or the worst, drought seen in this state.

The mid-1950's saw Montana with a period of reduced rainfall in the eastern and central portions of the state. In July of 1956, four counties applied for federal disaster aid due to greatly reduced precipitation amounts since June of the previous year. By November of 1956, a total of 20 Montana counties had applied for federal drought assistance.

Montana found itself in another drought episode in 1961. By the end of June, 17 counties had requested designation as federal disaster areas due to lack of moisture, higher than normal temperatures, and grasshopper infestation. Small grain crops died before maturing, and range grass and dryland hay crops were deteriorating rapidly. Livestock water supplies were at critical levels. In July of 1961, the State's Crop and Livestock Reporting Service called it the worst drought since the 1930's. Better conservation practices such as strip cropping were helping to lessen the impacts of the worst water shortages since the 1934-36 years.

By August of 1961, 24 counties had applied for federal drought disaster aid. The state was eventually awarded $420,000 under a federal cost-sharing program where funds were to be used for digging wells, building fire guards, conserving irrigation water, and implementation of wind erosion protection practices.

Five years later in 1966, the entire state was experiencing yet another episode of drought. Although water shortages were not as great as in 1961, a study of ten weather recording stations across Montana showed all had recorded below normal precipitation amounts for a ten month period. By August of 1966, the Bitterroot Valley was experiencing its worst drought in 25 years, and the state arranged to sell water to local irrigators.

A seven month survey ending in May of 1977, estimated that over 250,000 acres of Montana farmland had been damaged by winds. Inadequate crop cover and excessive tillage practices had resulted in exaggerated soil damage due to in-adequate soil moisture supplies. This drought episode was most severe in the western and south-central parts of the state.

Water supplies were so critical by June of 1977, that officials from Montana were working with others from Idaho, Washington, and Oregon on the Northwest Utility Coordinating Committee in an attempt to moderate potential hydroelectricity shortages. On June 23, Governor Judge issued an energy supply alert and ordered a mandatory ten percent reduction in electricity use by state and local governments.

Eastern Montana found itself with another well established drought episode in 1980. The southeast corner of the state had received less than four inches of precipitation since July of 1979. In the northeast corner of the state, Glasgow received only 4.74 inches in the period from June of 1979 to May of 1980, making it the driest 12 month period on record since 1905. Grasshopper infestations were seen in isolated areas, little wheat was planted, and large numbers of livestock were being sold due to the hay and water shortages.

By October, estimates of 1980 federal disaster payments were five times those paid in 1979. In Richland County alone, 600 of the county's 800 farmers had applied for federal payments. Total drought related economic losses for Montana in 1980 were estimated to be $380 million.

The drought that had started in 1979 continued into 1981. March snowpacks were at 50-60 percent of normal, initiating forecasts of critical water shortages later in the season. All areas east of a north-south line running from Havre through Billings had received less than their normal precipitation in the first three months of 1981. Wolf Point had received only six inches since June of 1979. Fortunately, large May storms brought moisture to much of the state, but then flooding started to occur in the

formerly parched areas. The northeast corner of the state, where forty percent of Montana's wheat crop is produced, remained the driest area of the state, despite the spring storms.

Inadequate moisture supplies were again the problem in 1984. By July, many of the Hi-Line cities were experiencing water shortages and rationing schedules were put into effect. Conrad businesses voluntarily closed to help curtail water use. The seven districts involved in the Milk River Irrigation Project were out of water, and crop losses were estimated at $12-15 million. August of 1984 saw Montana in flames with numerous forest and range fires burning out of control.

Drought continued to plague the state in 1985. All 56 counties received disaster declarations for drought during this year. April estimates by the Montana Crop and Livestock Reporting Service put the state's pasture and range at 65 percent of normal, while conditions in the northeast corner of the state were down to 32 percent of normal. From 1982 through 1985 cattle herds were reduced by approximately one-third.

The continued lack of moisture in 1985 resulted in a wheat crop which was the smallest in 45 years. Grain farmers received more in government "deficiency payments" and insurance money than they did for their crops. For a "typical" 2500 acre Montana farm/ranch, the operator lost more than $100,000 in equity (collateral, borrowing power) over the course of that year. The state's agriculture industry lost nearly $3 billion in equity.

The extended effects of this drought included the loss of thousands of off-farm jobs, the closing of many implement dealerships and Production Credit Associations (Gilles, 1985).

## PREDICTION POTENTIAL FOR RECURRENCE

Droughts are most often predicted only after they are well established. The National Weather Service issues seasonal forecasts for expected precipitation amounts, but these long-term forecasts are somewhat limited in their accuracy, and should not be taken as the final word on next season's drought conditions. They can serve as warning signals to be aware of other drought warning signs that can be watched and used as guidelines in water related management programs.

Establishment of a "normal" or "average" amount of precipitation is very dependent on what span of time is chosen. Normal precipitation amounts used in the USDA's monthly publication of climatological data are 30 year running averages, that are adjusted every ten years. In a relative sense, these averages are useful. The biggest problems come when these normals are used to predict how much precipitation should be expected. In a relative sense, a farmer in eastern Montana should expect to receive about as much precipitation as last year but, at the same time, should not be surprised if that "last year" amount turns out to be what the average was 30 years ago. Using the data available for Glasgow, Great Falls, and Miles City since 1897, the following results are obtained:

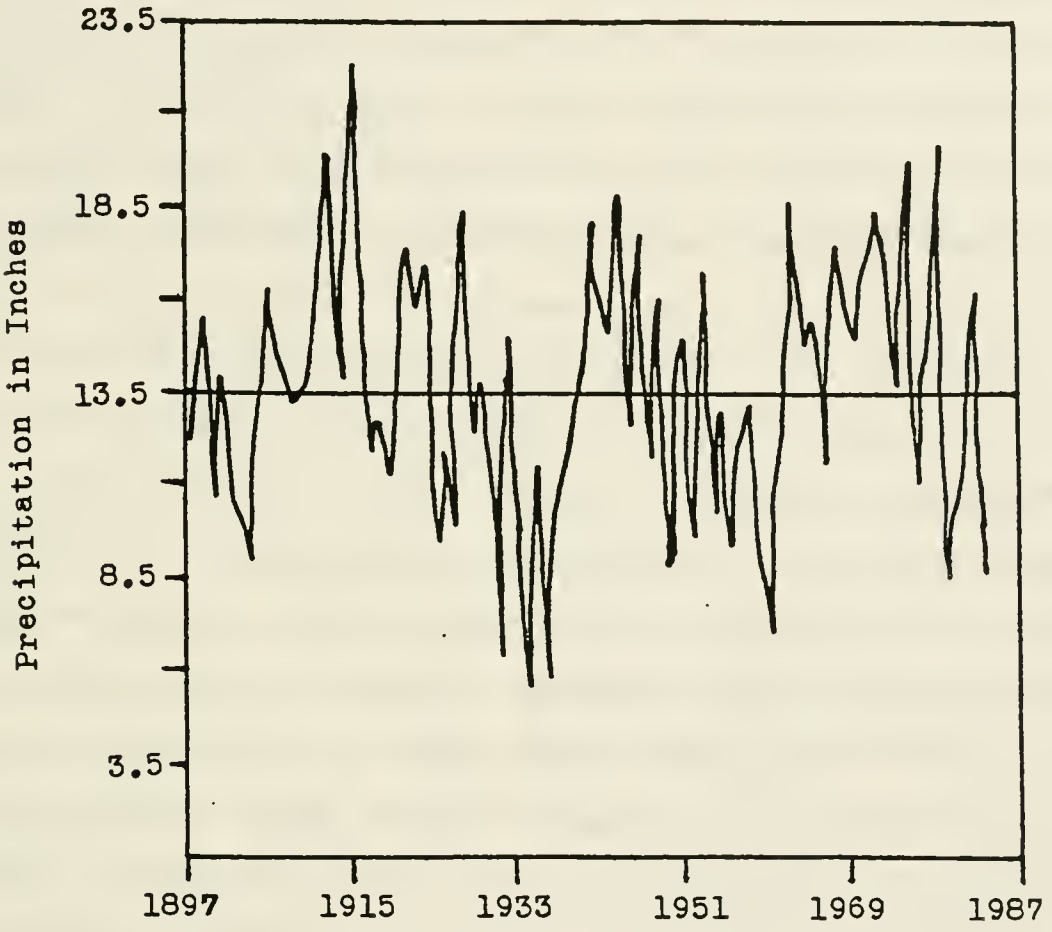
| Station | Average Precipitation | Standard Deviation |
|---|---|---|
| Glasgow | 12.5 inches | 3.9 |
| Great Falls | 15.1 inches | 3.9 |
| Miles City | 13.5 inches | 3.6 |

The standard deviation means that, statistically, Glasgow residents can expect that for two-thirds of any given period of time their annual precipitation will be between 16.4 inches and 8.6 inches. This type of variability in precipitation is especially important in semi-arid climates

like that of eastern Montana. Where total amounts tend to be less than 15 inches per year, a small amount of variability can constitute a large percentage of the total. Figure 2 illustrates how the precipitation in Miles City varied around the long term average of 13.5 inches from 1897 through 1984. There are also warning signs available for shortages of water reserves other than soil moisture. The Soil Conservation Service provides snow survey data for Montana throughout the winter and spring snow seasons. Montana's snowpack provides almost 70 percent of spring and summer streamflow throughout the state. If seasonal snowpack is below 60 percent of normal, then it can be expected that streamflow will be less than half of what it normally is during the spring and summer months. These types of projections are essential in managing irrigation and hydroelectric projects throughout the state, and are vital in fish, wildlife, and other recreational management. The mountainous areas of western Montana receive higher levels of precipitation, and therefore are not as susceptible to variability in annual precipitation. This does not, unfortunately, make the western regions any less susceptible to large scale droughts.

Analyzing the causes of drought is another means considered in predicting recurrence. Long-term weather patterns, such as droughts, are the result of complex global weather patterns. Due to this complexity, climatologists and meteorologists still do not agree on exactly what causes drought. Part of the complexity has to do with the long term cycles involved in shaping the global weather picture. Smaller cycles are often superimposed over longer term cycles which make the global picture even more unclear.

**Figure 2:** Miles City Precipitation 1897-1984 (Schmid, 1985):




Climatologists have studied droughts to try to determine if any recognizable cyclic pattern emerges. The most convincing pattern to be seen so far is an 11 and 22 year recurrence that corresponds to sunspots cycles. This pattern has gained support because solar energy is the major driving

force behind global atmospheric circulation, and sunspot cycles do reflect fluctuations in the amount of solar energy the Earth and its upper atmosphere receive. The biggest problem climatologists have in accepting the drought-sun spot cycle is the length of available records. Many feel that available records are not long enough to make the drought-sun spot cycles statistically significant. A statistical analysis of Miles City precipitation data from 1897 to 1984 does show a definite 22-25 year cycle of drought recurrence, with a much weaker trend seen every two to three years.

The problem of relying on short term precipitation averages and the difficulty of establishing proof of recurring drought cycles both point out the importance of finding some long-term records of past climates. Tree-ring study techniques are becoming more sophisticated, and therefore more useful in the analysis of past climatic conditions. Trees can live for generations, and record yearly weather conditions in their growth rings. Tree ring analysis can extend weather records well into the past. This is especially important in a state like Montana where weather records are limited because it has been settled for a relatively short period of time.

These types of long term records are essential in establishing patterns of drought occurrence. Whether or not a regular cycle can be established for drought recurrence in Montana, an established record of occurrence helps to show that drought is something to be expected. Long-term records can also be important in establishing the severity of drought to be expected. Both the recurrence intervals and the severity are important aspects of any type of long-term plan to help mitigate the effects of drought on Montana.

## STATE VULNERABILITY TO DROUGHT

Since Montana's population and water usage is continuing to grow, demand for water is rising at a steady rate. Available supplies have also increased over the years through a variety of structural (dams) and non-structural (conservation) means, but the State's ability to create new levels of supply is marginal. In recent years, demands on water have been increasing faster than supplies, so that tolerance to deal with water shortages is diminishing. The balance between supply and demand is likely to be disrupted more and more frequently, and in the future, water shortages are likely to be more frequent and costly.

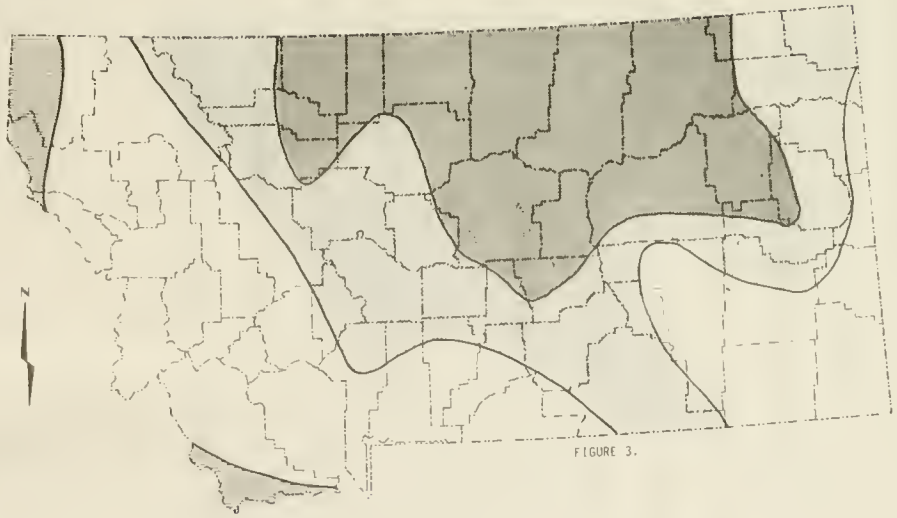
It is difficult to assess Montana's overall vulnerability to drought since it affects all levels of water use. However, the effects of water shortages are seldom disastrous in most sectors. For example, drought may have an economic impact on water-based recreation, but, the effect could hardly be considered a disaster. Similarly, drought seldom has a disastrous effect on municipal water supplies with the exception of a few areas of the state where systems have experienced historical water depletion problems. According to Dan Fraser (Environmental Sciences Division), municipal water shortages are most often the result of overuse. People anxiously anticipating predicted drought episodes tend to use more water. Those localities with a history of drought-induced depletion problems may expect future shortages and should place emphasis on mitigative strategies (e.g., ration groundwater use since it is a more reliable source) (Fraser, 1986).

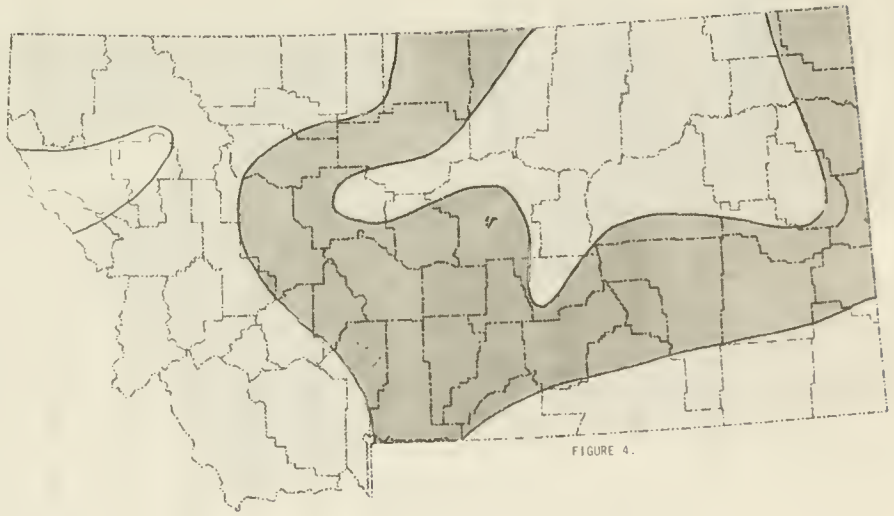
As revealed earlier in this section, the most significant impacts of drought are felt by agricultural users. The northeastern quarter of the state has proved historically to be most susceptible to drought followed by the southeastern quarter (Ralph Peck, 1986).

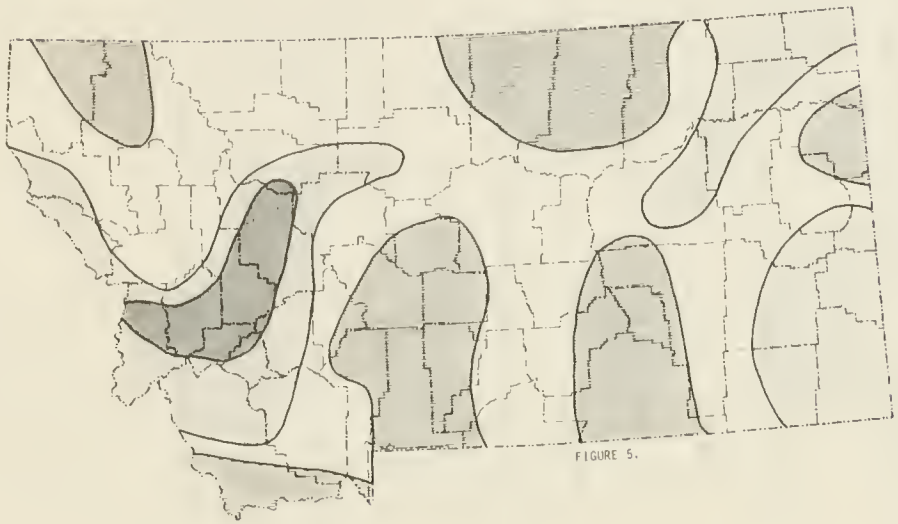
It is difficult to graphically depict drought vulnerability since so many variables are involved. Precipitation during the growing season (April to July) seems to be the most critical variable and as such was chosen, for the purposes of this document, to demonstrate drought vulnerability in Montana. Figures 3, 4 and 5 show growing season precipitation for the state in 1984, 1985 and 1986. The maps for drought years 1984 and 1985 show somewhat similar configurations and probably indicate those areas which may expect the greatest impact during low moisture years. There is a marked contrast between these maps and the growing season precipitation map for 1986. During the 1986 growing season more than three-fourths of the state received normal to above-normal amounts of precipitation (Giles, 1986). Never-the-less there are three areas of the state which received below normal amounts of growing season precipitation in 1986.

From these maps it becomes obvious that any part of the state may be subject to below normal precipitation and as such should be considered vulnerable to drought.

A systematic and timely application of limited resources, when utilized on the basis of a clear understanding of existing or potential impacts, can reduce drought effects. Should drought intensify to the point where broad scale impacts exceed state and local response capabilities, the state program for the mitigation of drought impacts would facilitate a request for federal assistance (Montana Disaster and Emergency Services Division, 1985).




Figures 3, 4 and 5. Growing season precipitation for Montana in 1984, 1985 and 1986 respectively.

Source: Great Falls Tribune, Farm and Ranch Trib, July 29, 1984, p. 16 and July 20, 1986, p. 6.

- Above Normal
- Normal
- Below Normal
- Much Below Normal

## MITIGATION

With the realization that drought is an inevitable part of life in Montana, the important issue is, what to do to lessen its effects. Since it is a difficult phenomenon to predict ahead of time, the best approach to mitigation is implementation of water conservation practices.

As mentioned earlier in the historical summary of Montana's droughts, agricultural practices have improved through the years so that the adverse effects of severe moisture shortages have been reduced somewhat. Because soil moisture is an important moisture reserve, soil conservation programs are also water conservation program. Leaving stubble as a mulch on fields in the fall catches and holds more moisture in the form of snow, and also keeps soil from being blown away. Strip cropping helps to reduce wind erosion during the growing season while providing a more efficient use of soil moisture than straight fallow in areas prone to saline seep. Planting shelter belts also serves as a means to reduce erosion.

In connection with the PDSI, calculations can be made to determine the amount of precipitation needed to bring the moisture balance to near normal. These figures are available during the growing season, along with the bi-monthly PDSI, in the USDA's Weekly Weather and Crop Bulletin. These figures could be useful in determining if a drought episode is severe enough to make planting of nonirrigated grains impractical. If the precipitation deficits are beyond reasonable seasonal amounts, chances are good that small grains planted would not provide economic yields. Depending upon the severity of the moisture shortage, grain varieties not usually planted in years of good precipitation due to their relatively low yields, might be considered

because of their ability to maintain adequate yields under low moisture conditions. If moisture deficits are beyond reasonable expectations, below normal yields could be expected from nonirrigated hay acres, and reductions in livestock herds could be considered. Such examples of management decisions associated with soil moisture reserves in Montana are numerous.

In good moisture years, it is more difficult for farmers and ranchers to see the benefits of conservation practices because soil moisture is not always an asset reported on economic statements. A public information program about the drought hazard in Montana is the best way to ensure good water management in the agricultural sector.

Wise forest management is also important in mitigating the effects of drought. Thoughtful lumbering practices will ensure an adequate supply of trees on the slopes to catch and hold the snowpack through the critical seasons. Revegetation of logged areas is important for the same reasons. Management in these watershed areas directly affects the amount and quality of water that enters into Montana's rivers and streams, and subsequently its lakes and reservoirs.

Once the water is into the rivers, lakes, and reservoirs, its conservation becomes the responsibility of those drawing from those reserves. Water conservation at the residential, commercial, municipal and industrial levels should focus on management of both supply and demand. Supply management programs may consist of metering, leak detection and repair, pressure reduction, watershed management and evaporation suppression. Demand management programs may include pricing, regulation and education. Further information on those programs is available in "Before

the Well Runs Dry, a Handbook for Designing a Local Water Conservation Plan" (see literature cited).

Like farmers and ranchers, the above users can only be expected to manage wisely if they are well informed about the resource they are dealing with. Adequate information on snowpack and available soil moisture is essential to these people. Again, some method of educating water managers in drought mitigation techniques is highly advisable.

Augmenting natural precipitation is another option available for lessening the effects of drought. Although not in widespread use at the present time, it is not a practice that should be ignored in the future. As technology improves, cloud seeding is becoming better understood, enabling it to become more effective.

One of the most effective mitigation techniques is planning. In 1985, the Montana Division of Disaster and Emergency Services revised the Montana Drought Plan. The purpose of this plan is to provide an effective and systematic means for the State of Montana to deal with emergency drought problems which may occur over the short or long term. Briefly, the plan establishes two systems: Assessment and Response. The assessment system involves designated agencies utilizing a broad range of information sources, gathering and evaluating data and providing for the delineation of problem area needs which cannot be met on the local level. As needs are assessed, response consists of any action taken by state agencies to address those needs. To deal with unusually complex needs, the Montana Disaster Advisory Counsel (comprised of senior management representatives in State Government and chaired by a representative of the Governor) was established. Counsel

duties are to review impact statements, recommend solutions, ensure inter-agency coordination, and provide recommendations for further action to the Governor. If necessary, recommendations are made to the Governor for state legislation or federal assistance.

Further research is needed to enhance future drought planning efforts in the following areas:

- Dissemination of drought information to the public.
- Solicitation of local government and private sector assistance during drought episodes.
- Other state drought mitigation strategies.
- Statutory options for increasing the emergency powers of the Governor during drought situations.
- Efficient water use techniques.
- Drought probability studies.
- Evaluation of costs and benefits of cloud seeding.
- Short and long-term secondary drought effects - both economic and environmental.

## SUMMARY

Drought is a special type of disaster because its occurrence does not require evacuation of an area nor does it constitute an immediate threat to life or property. People are not suddenly rendered homeless or without food and clothing. The basic effect of a drought is economic hardship, but it does, in the end, resemble other types of disasters in that victims can be deprived of their livelihoods and communities can suffer economic decline.

At least 50 percent of the state's electricity comes from hydroelectric generators. Over one million acres under irrigation are harvested each year. Dryland farming and ranching continue to contribute a large percentage to the state's agricultural production. Forestry supports a significant segment of the population. Recreation not only brings in out-of-state dollars, but is a very important part of life to Montanans as well. All of these functions require adequate supplies of water.

Meteorologists and climatologists have established that droughts are a natural part of the global climatic cycle, and that it is not unusual for them to be severe and prolonged in semi-arid areas like Montana. Their severity can be aggravated by the improper use and management of water and related resources such as soils and forests. People using these resources in Montana must have adequate information available to them in order to make wise management decisions.

## REFERENCES


Civil Defense Division, 1976, Hazard/vulnerability analysis: MT Disaster Preparedness Program, pp. 11-13.

Gilles, T.J., 1985, The 1985 drought ... If it's over, what next?: Montana Magazine, November-December 1985, pp. 39-40.

Great Falls Tribune, July 6, 11, 1956, November 22, 1956, June 29, July 14, 29, 1961, July 20, August 3, 22, 1966, June 23, 24, 1977. May 28, June 8, 29, October 16, 1980, February 22, March 6, April 20, May 3, 24, 1981, July 19, 20, 26, 31, August 11, 1984.

Fraser, D.L., P.E., Supervisor Drinking Water Program, Montana Department of Health and Environmental Sciences, 1986, Personal communication.

Karl, T.R., 1983, Some spatial characteristics of drought duration in the United States: Journal of climate and applied meteorology, Vol. 22, No. 8 (August 1983), pp. 1356-1366.

Landsberg, H.E., 1982, Climatic aspects of droughts: Bulletin of American Meteorological Society, Vol. 63, No. 6 (June 1982), pp. 593-596.

Magnuson, M.D., 1967, Meteorological drought in Montana: U.S. Department of Commerce, Environmental Science Services Administration.

MT Disaster and Emergency Services Division, 1985, Montana Drought Plan.

New England River Basins Commission, 1981, Before the well runs dry - A handbook for designing a local water conservation plan: U.S. Government Printing Office, pp. 95.

Schmid, G., 1985, Drought hazard in Montana: Unpublished report, Earth Sciences Department, Montana State University, Bozeman, MT, pp. 9.

United States Department of Agriculture, 1984, Montana Agricultural Statistics, Vol. XXI.

United State Department of Commerce, Climatological data, Montana. Vol. 1-Vol. 87 (1897-1984).

## REFERENCES - Continued

_____, 1985, Weekly Weather and Crop Bulletin, Vol. 72, No.'s 1, 5, 9, 12, and 15.

Warrick, R.A., 1975, Drought hazard in the United States - A research assessment: University of Colorado, Institute of Behavioral Science, Boulder, CO.

# VECTOR - BORNE DISEASES

## DESCRIPTION

"Vectors are organisms (e.g., insects, animals, etc.) which may adversely affect the public health and well-being by directly or indirectly transporting or transmitting a disease-causing agent, or which may cause other health trauma" (Moy and Quickenden, 1976). Vector-borne diseases which have been diagnosed in Montana include: Western equine encephalitis, St. Louis encephalitis, Colorado tick fever, Rocky Mountain spotted fever, tularemia, rabies and plague.

## WESTERN EQUINE ENCEPHALITIS

This disease is primarily associated with birds rather than horses, so the term "equine" is misleading. Historically, the virus involved horses; however, it occurs in several host animals only a few of which (horses, mules, humans) suffer acute illness from it. Although birds are considered the primary virus host, they usually do not show disease symptoms (Collins, 1963).

The principle vector of Western Equine Encephalitis is the locally abundant mosquito Culex tarsalis. It seems to prefer birds in the spring, but switches feeding preference to humans, horses and many other vertebrates by mid-summer. This vector is easily infected and breeds in large numbers in both natural and irrigation overflow water, in sites visited by birds and mammals and near human activity (Collins, 1963).

Cool, wet springs and floods are major contributing factors to increased incidence. The mortality rate from Western Equine Encephalitis is approximately 2-4 percent (Montana Civil Defense Division, 1976); more than

half of affected infants suffer permanent brain damage or death (Center for Disease Control, 1978).

## ST. LOUIS ENCEPHALITIS

The mosquito, Culex tarsalis, is also the primary disease vector of St. Louis encephalitis in Montana. Limited available data indicates that wild birds are the most likely hosts of the St. Louis virus. Chickens may also be host reservoirs.

As expected, the seasonal prevalence of this disease coincides with times when mosquito breeding conditions are favorable (Collins, 1963). Outbreaks appear to be favored by heavy spring rains followed by hot, dry summers. As with Western Equine Encephalitis, floods amplify the hazard.

In many St. Louis Encephalitis epidemics the incidence has been highest in individuals over fifty years of age (Collins, 1976). The mortality rate for St. Louis Encephalitis in Montana varies from 5 to 30 percent (Montana Civil Defense Division, 1976).

## COLORADO TICK FEVER

The Rocky Mountain wood tick Dermacentor andersoni is the vector responsible for transferring Colorado tick fever to man. The virus is maintained in nature by the immature stages of this tick and its small mammalian hosts (golden mantled ground squirrels, Columbian ground squirrels, porcupines, deer mice, chipmunks, pine squirrels, and field mice). In certain areas, the virus has been recovered from as many as 40 percent of the ticks (Rocky Mountain Laboratory, 1974).

The usual months in which the disease may be expected are April to July. Infection rates are higher in moist mountainous areas than in dry, sagebrush covered plains (Eklund, 1963).

## ROCKY MOUNTAIN SPOTTED FEVER

Rocky Mountain spotted fever is potentially the most serious of the tick-borne diseases. The microorganism which causes this disease is found in the body of 1-3 percent of ticks (occasionally up to 11%) (Quickenden, 1982). Ticks of several species may be infected, however two, Dermacentor andersoni and Dermacentor variabilis, are of the greatest importance in transmitting the disease to humans in North America (Dyer, 1963). The disease is transferred to humans when ticks attach themselves and become engorged with the hosts blood. The likelihood of being infected with the disease is directly related to the amount of time the tick remains attached. Up to ten percent of the cases are fatal if medical attention is not sought.

As previously mentioned, ticks become active in early Spring and return to hibernation in late June or early July. The largest tick population can probably be found in the western one-third of Montana; however, this vector may be found in mountainous, wooded and sagebrush areas throughout the state (Quickenden, 1982).

## TULAREMIA

Tularemia is primarily a disease of rabbits, beavers, voles and other rodents, but may be found in other vertebrate species. Vectors capable of transmitting the disease are numerous, including several species of ticks, and biting flies. Mosquitoes, deer flies and mites have been found to be naturally infected.

Tularemia can be transmitted by a number of different routes, probably more than any other infectious disease. About 90 percent of human cases in the United States may be attributed to contact with infected rabbits or their carcasses.

Ticks are an increasing source of infection; the wood tick has caused many cases of tularemia in Montana. The disease may also be acquired through contact with a number of wild and domestic animals and birds as well as through exposure to contaminated water or food and dust.

Most human cases are reported during the months of April through October since this is the period during which contact with infection sources is most likely. The fatality rate is under two percent in the U.S.A. (Shaughnessy, 1963).

## RABIES

All warm-blooded animals are susceptible to rabies. Dogs serve as the main vector of the disease. Wild animals, principally skunks and bats are frequently found to be transmitters. Nearly all cases of this disease result from the entrance of the rabies virus to a wound caused by the bite of a rabid animal.

The conditions under which rabies is transmitted are no more favorable at one time of year than another. Rabies is fatal. No one has recovered from the disease after clinical symptoms have begun (Tierkel, 1963).

## SYLVATIC PLAGUE

Sylvatic plague is referred to as "animal" plague since it affects primarily wild rodents and rabbits. Rodent fleas serve as vectors of this disease. Fleas feed on infected animals and then convey the disease either from animal to animal, animal to humans, or person to person.

Plague manifests itself in humans in various forms. The two chief types of clinical plague are bubonic and pneumonic. Bubonic plague usually affects only people in tropical or semitropical climates. Pneumonic plague, more commonly occurs in cold and temperate climates and is the more likely

hazard in Montana (Meyer, 1963). The untreated mortality rate for the bubonic form is 60-65 percent; and for the pneumonic form is 95-100 percent.

## HISTORICAL OCCURRENCE AND RESPONSE

To date, the greatest number of Western equine encephalitis cases on record in Montana occurred in 1965 with 333 cases reported in horses and 12 in man (Quickenden and Jamison, 1979). The number of cases varies from year to year (see Figure 1).

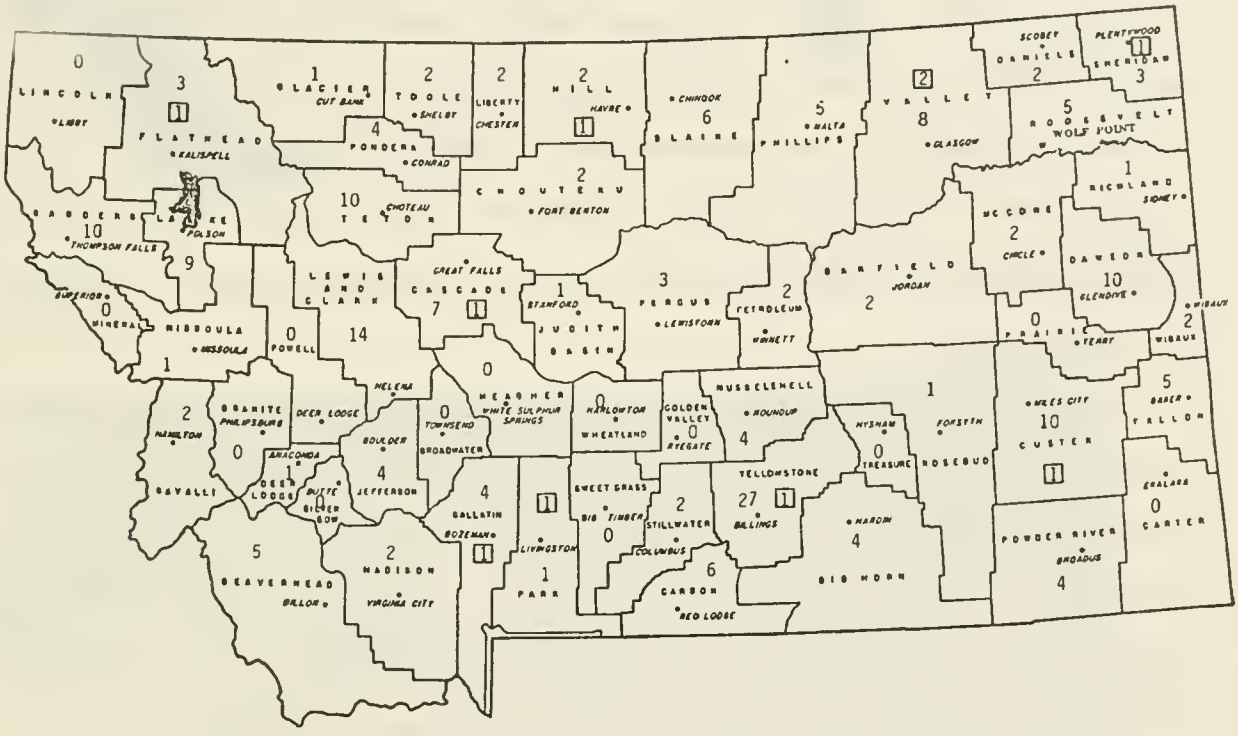



**Figure 1:** Laboratory confirmed cases of Western Equine Encephalitis (1975, 1977, 1979, - 1984). Horses = 207 Cases Human = 10 Cases (Quickenden, 1986)

For unknown reasons, clinical expression of St. Louis encephalitis in Montana has been fairly low. However, health screening clinics indicate that more individuals in the higher mountainous areas have reacted to St. Louis Encephalitis antibodies than Western Equine Encephalitis antibodies (Montana Civil Defense, 1976).

Every year physicians diagnose a number of cases of Rocky Mountain spotted fever and Colorado tick fever. From 1981-1985, there were 38 cases of Rocky Mountain spotted fever and 74 cases of Colorado tick fever (Quickenden, 1982, 1984, 1986; Wibaux Pioneer-Gazette, 1986). Ken Quickenden, Medical Entomologist and Sanitarian with the Department of Health and Environmental Sciences, estimates that only roughly 10 percent of cases are reported to the state each year.

Colorado tick fever has been a problem chiefly in the southwestern quarter of the state while Rocky Mountain spotted fever has historically been most intense in the southern half of the state (Quickenden, 1986 and Jellison, 1945). Cases of Tularemia have been less abundant and appear to be predominantly associated with ticks in the southeastern part of the state (Quickenden, 1982).

No cases of human plague have been reported in Montana, however, plague antibodies found in wild carnivores and dogs serve as evidence that bacteria does exist endemically in some counties (See Figure 2). Plague is not expected to be an epidemic problem in Montana. Hunters, campers and persons occupationally exposed to carnivores, rodents and their fleas may contract sporadic cases of endemic bubonic plague (Quickenden, 1986).

Infrequent outbreaks of animal rabies were reported in domestic species (primarily dogs) in Montana prior to the mid-1960's. In 1964, the first case of skunk rabies was diagnosed. Since that time 11-1200 cases have been diagnosed in 36 counties (Ferlicka, 1987). The majority of these cases occurred in north-central and eastern Montana (See figure 3).

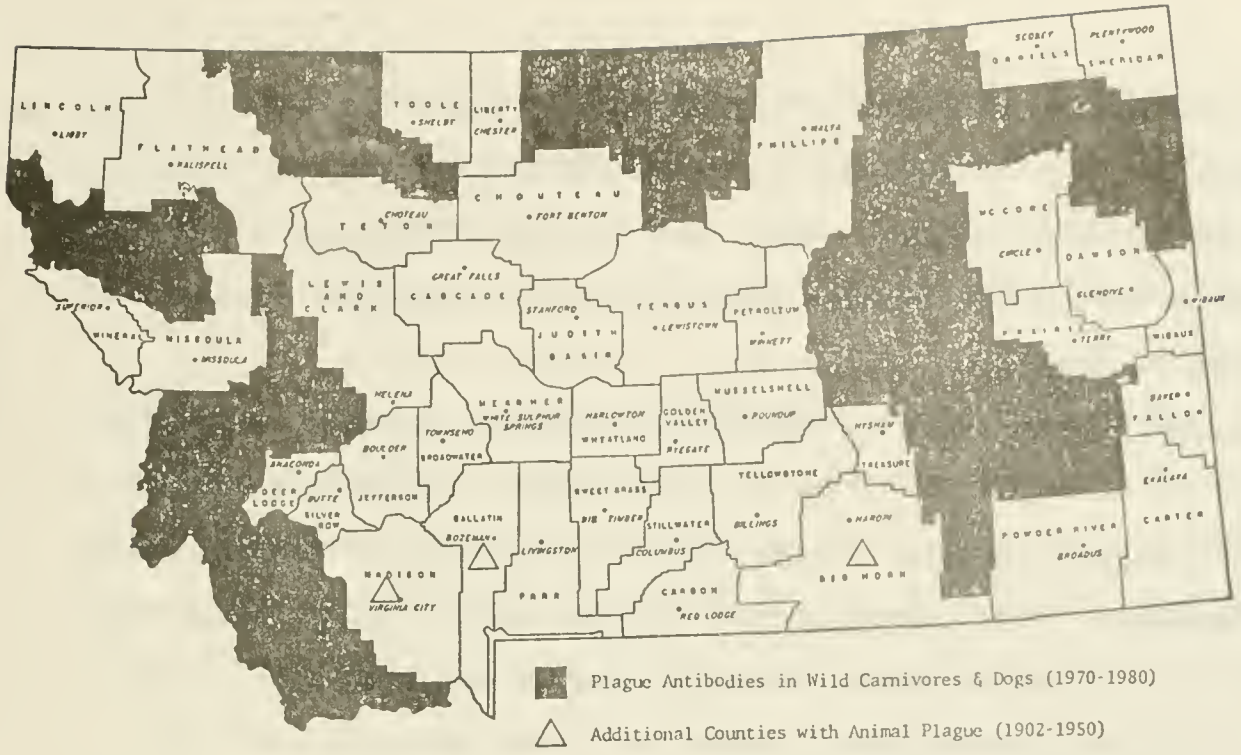



**Figure 2:** Sylvatic (animal) plague activity (1902-1980) (Quickenden, 1986).

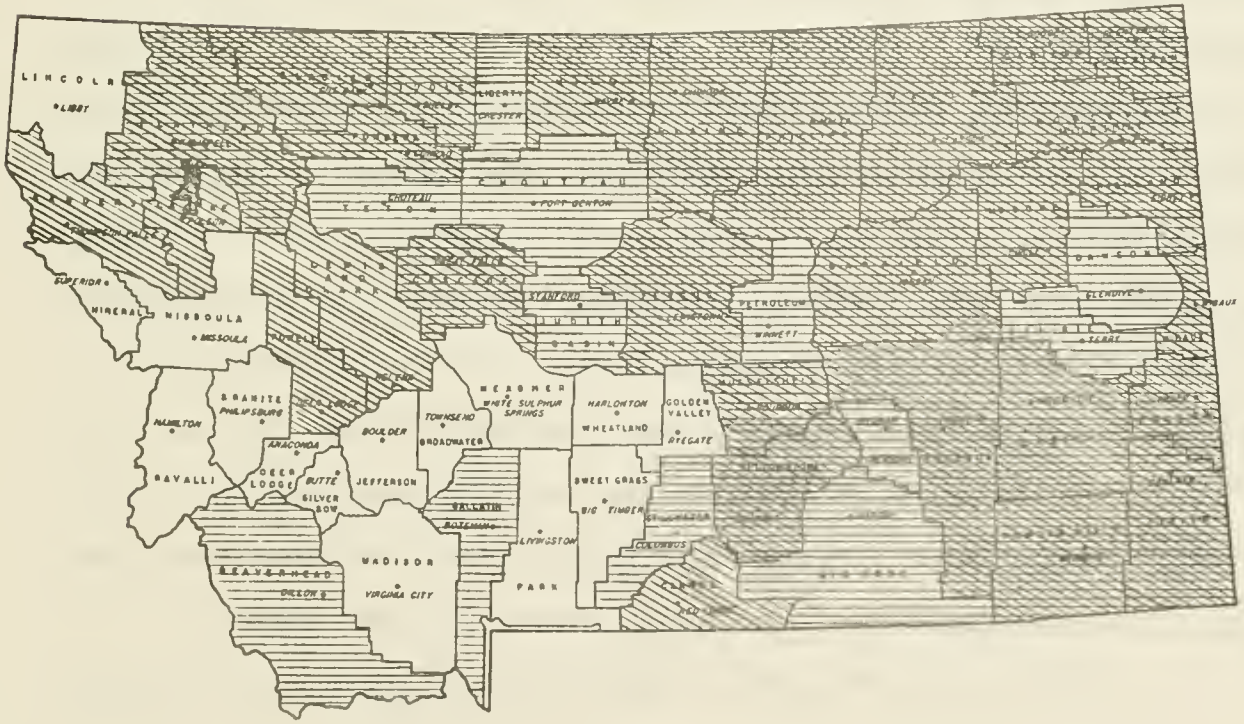



**Figure 3:** Rabies cases diagnosed since 1964.
Other than skunk or bats.
Skunk

In Montana, skunks are the primary hosts for this disease which may have come from known skunk rabies areas of Saskatchewan and North and South Dakota (Sullins, 1981). Dogs, domestic cats, cattle, bats, badgers and sheep have also been found rabid in the State (Montana Department of Livestock, 1973).

Skunk rabies control measures (a program of trapping and shooting) begun during the spring of 1973 by the Department of Livestock proved to be ineffective and costly. In January 1975, the Department adopted a formal Skunk Rabies Control Policy which outlines approaches to skunk rabies control and/or surveillance. The current method of control involves the use of strychnine - treated eggs to reduce skunk populations (Sullins, 1981).

**PREDICTION POTENTIAL FOR RECURRENCE**

As long as vectors are present in the state, the potential for recurring disease exists.

A number of factors influence this potential: areas of historical occurrence, time of year, vector habitat availability and incident of human exposure.

Conditions that indicate increased potential for the spread of mosquito-borne encephalitis include:

Large adult vector populations occurring in an area of recent encephalitis virus activity prior to about July 10;

Large larval vector populations found in areas of recent encephalitis virus activity prior to about June 21;

Large adult vector populations found to be infected prior to about August 1;

Water that has been standing on the surface at least five or six days, is less than two feet deep and is slow or stagnant (water less than six inches deep and containing emergent vegetation is particularly productive mosquito habitat). Flooding frequently contributes to the acreage of available habitat (Montana Department of Health and Environmental Sciences, 1981);

Data obtained from the State Department of Health and Environmental Sciences showing the level of encephalitis incidence in human populations or early expression of the virus in horses or chicken flocks (Montana Department of Health and Environmental Sciences, n.d.).

Potential recurrence of tick-borne diseases is more likely in the mountainous, wooded and sagebrush areas of the state. The activity period for ticks begins in early spring, when the snow melts and vegetation emerges, and usually lasts into late June or early July. Cooler temperatures in early summer encourage a longer period of tick activity. The potential for infection is greatest among individuals whose occupations or leisure-time activities expose them to tick bites (Quickenden, 1982).

Cases of skunk rabies have been diagnosed in all months of the year, however, 15 years worth of data has revealed that nearly 70 percent of diagnosed cases occur in April, May, June and July. This seasonal increase of the disease may be attributed to the increased contact of skunk courtships and mating (Sullins, 1981).

## STATE VULNERABILITY TO VECTOR-BORNE DISEASES

Based on historical incidence, the vector-borne diseases to which Montanans are most vulnerable are Western equine encephalitis, St. Louis encephalitis, Rocky Mountain spotted fever, Colorado tick fever and tularemia.

Reported cases of Western equine encephalitis have typically been higher in irrigated areas east of the Continental Divide (Montana Civil Defense Division, 1976). In most areas more than 90 percent of all mosquito production may be associated with the use of water for irrigation. In non-irrigated areas, snow melt pools, spring run-off into low areas or depressions and a rising water table account for a higher percentage of mosquitos produced (Department of Health and Environmental Sciences, 1981). Flooding creates additional breeding sites. These same areas may be considered vulnerable to the incidence of St. Louis encephalitis. The likelihood of this disease infecting the population is greater in the high mountainous areas of the state (Montana Civil Defense Division, 1976).

Colorado tick fever has historically been associated chiefly with the southwestern quarter of the state (See Figure 4) while cases of Rocky Mountain spotted fever have been most numerous in the southern half of the state (See Figure 5). As long as favorable tick habitat exists in these regions and within close proximity to populated areas, these portions of the state should be considered most vulnerable to future incidence of tick fever (Quickenden, 1986).

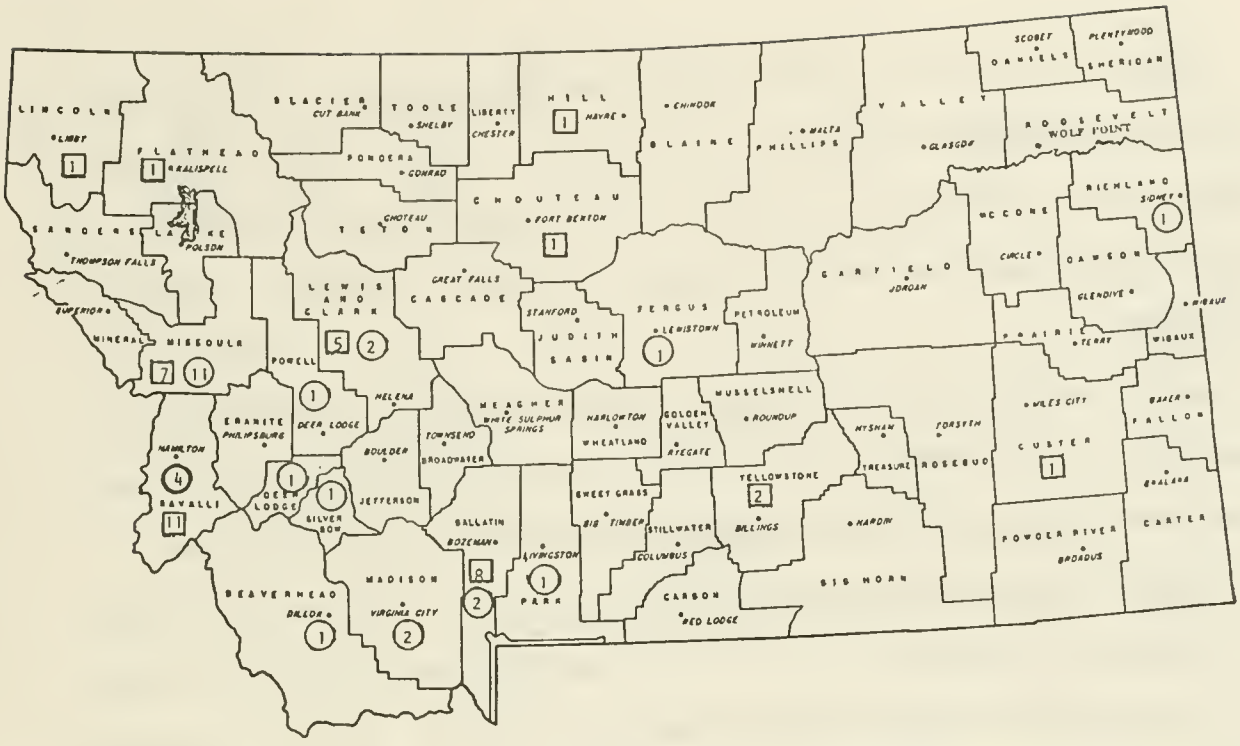



**Figure 4:** Reported cases of Colorado tick fever. (Quickenden, 1986)
1981-1982 = (28) 1970-1973 = [38]

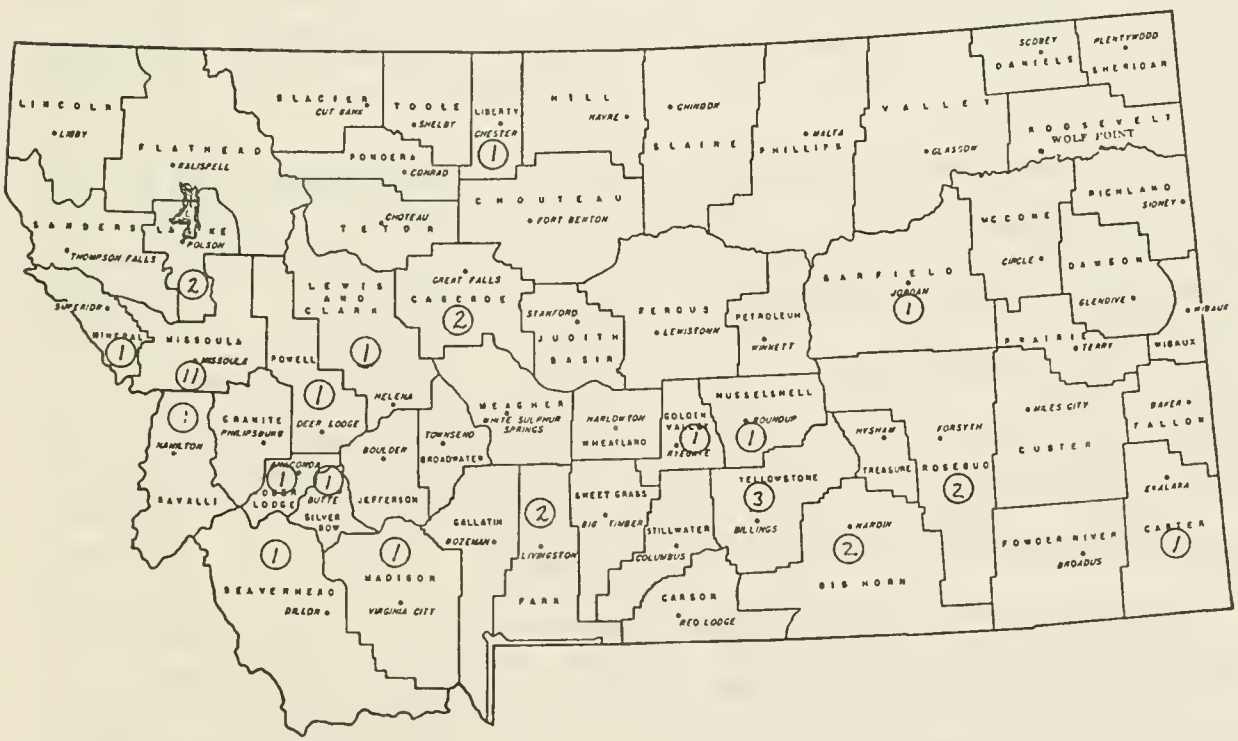



**Figure 5:** Reported cases of Rocky Mountain Spotted fever 1970-1972, 1980-1984. (Quickenden, 1986).

Most, but not all, cases of tularemia appear to be associated with ticks in the southeastern part of the state. As with the other tick-borne diseases caution should be observed in tick-infested areas in this portion of the state or when handling wild rabbits or rodents (Quickenden, 1985).

**MITIGATION**

Control of diseases transmitted by insect vectors is most effectively approached through control of the vector. This is not always possible, but, in the case of mosquito-borne diseases, vector control is a viable option.

Mosquito control districts (See Figure 6) have been organized under state enabling legislation (MCA, Title 7, Sections 7-22-2401 through 7-22-2448). These districts have program continuity, higher levels of financing and a more reliable source of financial support. Districts sponsor integrated mosquito management programs which have been effective in reducing pest and disease-bearing mosquito populations to acceptable levels.2

Integrated mosquito management involves combining management techniques which compliment each other while effectively controlling mosquito populations. These techniques fall into three categories: 1) Physical control (water management or source reduction); 2) Biological control; and, 3) Chemical control. One of the basic philosophies of mosquito control is that only by treatment of cause (larval mosquito habitat) rather than effect (mosquito populations) can a problem be reduced.

Physical control involves altering mosquito larval habitat through the removal of free, shallow, standing water. Source reduction may be accomplished through diking, ditching, draining, dredging, deepening, filling or water level management.

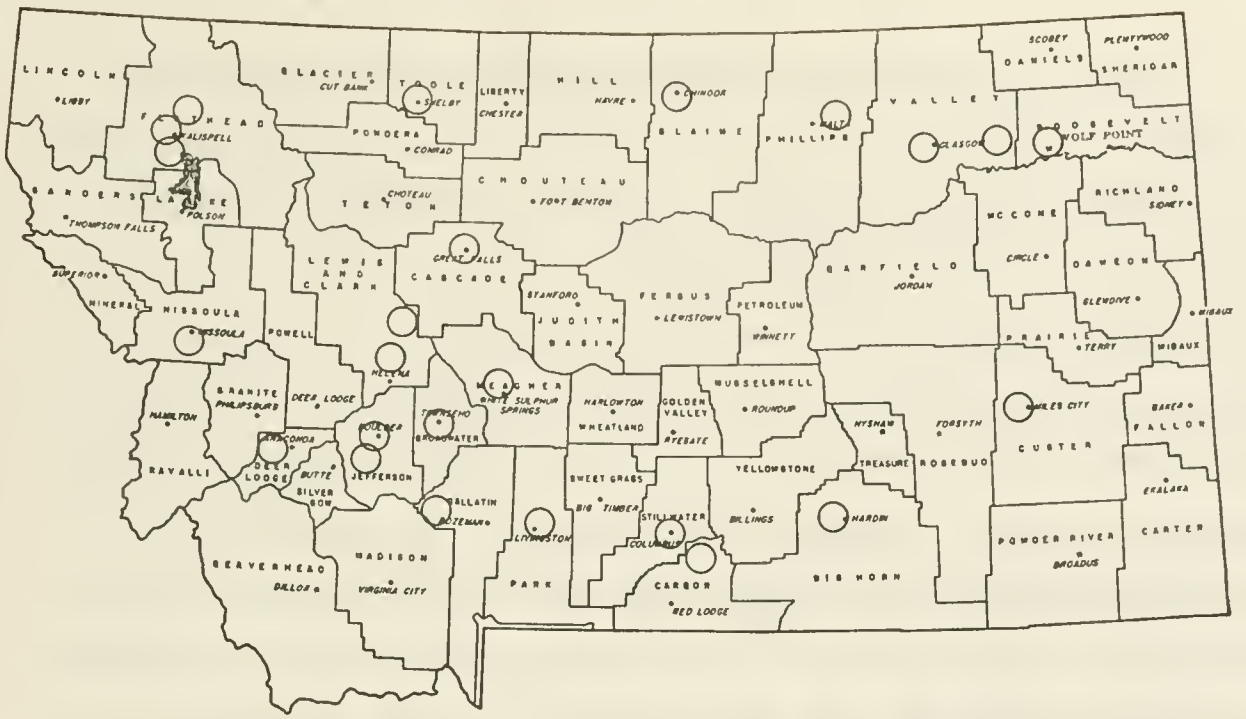



**Figure 6:** Organized mosquito abatement districts (Quickenden, 1986).

Biological control uses introduced or otherwise manipulated natural enemies to manage mosquito populations. The mosquito has numerous natural enemies, however, at present biological control is limited to the use of fish that feed on aquatic mosquito stages, and the use of biological preparations. Biological control may be integrated with physical control by such actions as constructing a system of ditches in a marsh to allow greater access of predators to mosquito larvae. Biological control is popular since it reduces pesticide usage, minimizes direct toxic effects to non-target organisms, and reduces mosquito populations that are resistent to insecticides.

Three levels of chemical control are used in mosquito management programs: 1) larviciding; 2) pre-larviciding or pre-hatch treatment; and 3) adulticiding. These practices should be compatible with other mosquito management activities.

In order to develop and implement an effective integrated mosquito management strategy, detailed surveys are essential. Survey and evaluation are continual processes that must accompany control (Montana Department of Health and Environmental Sciences, 1981).

In the case of mosquito-borne diseases, the vector is closely tied to humans, but when a disease has a reservoir of infection in wild animals and is transmitted by a vector that bites both those animals and human, control is more difficult. The vectors of plague, tularemia, Colorado tick fever and Rocky Mountain spotted fever cannot be effectively controlled on a statewide basis (Burrows, 1973). In selected land areas, direct application of registered pesticides gives excellent control of some vectors and intermediate hosts of these diseases (Benenson, ed, 1975).

Plague monitoring programs have been discontinued in Montana since no human cases have ever been reported (Quickenden, 1986). If, however, plague should ever become a problem in Montana, mitigation may be accomplished by: 1) appropriate sanitary measures directed simultaneously against the vectors and the rodent reservoir; 2) efforts to immunize the individual; and 3) strict isolation of the sick and the handling of all infectious material with care (Meyer, 1963).

The only mitigative measures suggested for tick-borne diseases involve the avoidance of ticks to minimize disease transmission. This may be accomplished through:

- avoiding known tick-infested areas, particularly where rodent burrows are evident;

- wearing clothing which fits snugly around ankles, wrists and waist while in infested areas;

- using insect repellents containing diethyltoluamide and/or dimethylphthalate;
- examining oneself and one's pets frequently to remove ticks;
- removing ticks immediately, without crushing.

If bitten by a tick, remove it, place it in a container and note the date found. If health problems develop, the live tick may expedite illness diagnosis (Quickenden, 1985).

As with all hazards, increasing public awareness of the existing and potential problems as well as the mitigation techniques which may be employed, is of utmost importance.

For further information, technical advice or assistance, the vector control specialist with the Montana Department of Health and Environmental Sciences may be contacted.

## SUMMARY

Potential vector-borne diseases in Montana are Western equine encephalitis, St. Louis encephalitis, Colorado tick fever, Rocky Mountain spotted fever, tularemia, rabies and plague. Based on historical occurrence, Montanans are most susceptible to the first five diseases listed above.

Control of these diseases varies depending on whether or not an intermediate host is involved. In the case of direct infection with a mosquito-borne disease, control is most effectively approached through management of the vector itself. Tick-borne diseases involve an intermediate reservoir of infection and therefore are more difficult to control.Avoidance tactics are the only suggested mitigative measures to date for minimizing tick-borne disease transmission.

A comprehensive public awareness program informing people of the disease potential and actions they might take to lessen their vulnerability would be the greatest step toward successful elimination of vector-borne diseases in this state.

## REFERENCES


Benenson, A.S., ed., 1975, Control of communicable diseases in man.

Burrows, W., Ph.D., 1973, Textbook of Microbiology: W.B. Saunders Co., Philadelphia, PA, pp. 275.

Center for Disease Control, U.S. Dept. HEW, 1978, Control of western equine encephalitis, 35 pp.

Collins, D.L., Ph.d., Sc.D., 1963, Arthropod-borne viral encephalitides, in Diseases transmitted from animals to man: Charles C. Thomas, Publisher, pp. 731-773.

Datta, F. (ed), 1986, Early ticks are causing some problems: The Wibaux Pioneer-Gazette, Wibaux, Montana, June 12, 1986.

Datta, F. (ed.), 1986, Local county agent offers tips on fighting mosquitos: The Wibaux Pioneer-Gazette, Wibaux, Montana, June 12, 1986.

Dyer, R.E., M.D., 1963, Rocky Mountain spotted fever, in Diseases transmitted from animal to man: Charles C. Thomas, Publisher, pp. 697-707.

Eklund, C.M., 1963, Colorado tick fever, in Diseases transmitted from animals to man: Charles C. Thomas, Publisher, pp. 786-791.

Ferlicka, D., 1987, Montana Department of Livestock, personal communication.

Jellison, 1945, Public Health Reports, v. 60: 958 - 961.

Meyer, K.F., D.V.M., Ph.d., M.D., D.Sc., LL.D., 1963, Plague, in Diseases transmitted from animals to man: Charles C. Thomas, Publisher, pp. 527-587.

Montana Civil Defense Division, 1976, Hazard/vulnerability analysis. Montana Disaster Preparedness Program, pp. 99-103.

Montana Department of Health and Environmental Sciences, 1981, Mosquito control training manual, Food and Consumer Safety Bureau, pp. 44.

Montana Department of Health and Environmental Sciences, n.d., Documentation necessary to obtain federal disaster assistance administration funds for mosquito control: Food and Consumer Safety Bureau, 1 p.

Montana Department of Livestock, 1973, Montana rabid skunk control emergency - environmental impact statement pursuant to Montana Environmental Policy Act Sec. 69-6504.

## REFERENCE - CONTINUED

Moy, R.F. and Quickenden, K.L., Ph.D., R.S. (eds.), 1976, Pesky pest news: Newsletter, Montana Department of Health and Environmental Sciences, Food and Consumer Safety Bureau, pp. 15.

Quickenden, K.L., Ph.D., R.S., and Jamison, V.C., M.A., 1979, Montana mosquitos: Part 1: Identification and biology: Vector control bulletin no. 1 (revised), Montana Department of Health and Environmental Sciences, Food and Consumer Safety Bureau, pp. 35.

Quickenden, K.L., Ph.D., R.S., 1985, News release, Montana Department of Health and Environmental Sciences, Helena, MT, March 13, 1985, pp. 4.

Quickenden, K.L., Ph.D., R.S., Medical Entomologist and Sanitarian, Food and Consumer Safety Bureau, Montana Department of Health and Environmental Sciences, 1986, Personal communication.

Rocky Mountain Laboratory, 1974, RML Circular No. 2.

Shaughnessy, H.J., Ph.d., 1963, Tularemia, in Diseases transmitted from animals to man: Charles C. Thomas, Publisher, pp. 588-604.

Sullins, M., 1981, Training manual for pesticide applicators involved in skunk rabies control and/or surveillance. Montana Department of Livestock and Montana Department of Agriculture.

Tierkel, E.S., V.M.D., M.P.H., 1963, Rabies, in Diseases transmitted from animals to man: Charles C. Thomas, Publisher, pp. 293-349.

# NUCLEAR ATTACK

## DESCRIPTION

Nuclear attack represents the most threatening man-caused hazard that could affect Montana. When a nuclear bomb explodes, there are three primary potential effects:

1. **The direct effects from blast overpressure.**

   When a nuclear weapon explodes in the atmosphere, the air surrounding the detonation point is rapidly compressed and forced outward. A blast or shock wave is created that initially moves at speeds much higher than the speed of sound. The amount by which the pressure produced by this wave exceeds normal atmospheric pressure is known as overpressure (FEMA, 1987a).

   Additional direct effects are initial nuclear radiation (INR) and the electromagnetic pulse (EMP). INR is that portion of nuclear radiation that appears during the first minute after the detonation of the weapon. This form of radiation may be hazardous to unprotected people within about 1.5 miles of a detonation.

   EMP is a short energetic pulse of electromagnetic radiation released by the weapon. The EMP effect resulting from a nuclear detonation within the earth's atmosphere is generally not significant. A surface or near surface burst generates an intense but mostly localized EMP near ground zero. The effects of blast, shock, nuclear and thermal radiation, however, usually outweigh any destructive capabilities of EMP in this region. High altitude bursts cause more extensive problems. When high yield weapons are

detonated outside the earth's atmosphere, an efficient conversion of nuclear energy into the electromagnetic frequency range occurs. This energy can affect the operation of unprotected electrical and electronic equipment over entire continents. Continued operation of the equipment is disrupted until it can be repaired or replaced. Equipment without electronic components, such as generators, motors and transformers, is less susceptible to EMP damage, while control systems and computers are highly susceptible to damage.

Many types of electrical/electronic equipment could be affected or even destroyed by the EMP from high-altitude detonations, but it is unlikely that any more than a small percentage overall will be damaged. The direct effect of EMP on people is limited to those who are dependent upon electrical life support systems (FEMA, 1987a).

2. **The fire risk.**

The combined effects of blast overpressure damage and the thermal pulse or fireball of a weapon can ignite exposed combustible materials, causing many sustained fires (FEMA, 1987a). Primary fires are those ignited directly by the thermal pulse of a nuclear detonation. Secondary fires are generated by damage and destruction from blast overpressures; these fires result from the disruption of building furnaces, gas lines, and electric lines (FEMA, 1986b).

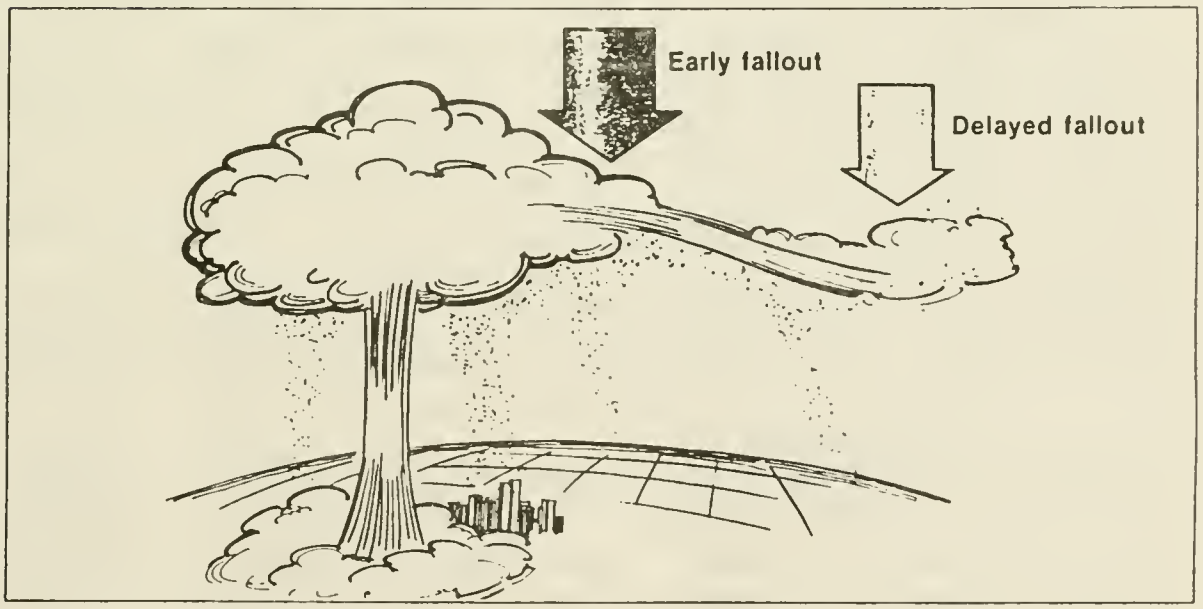
3. **The fallout risk.**

Fallout radiation generated by surface burst weapons presents unique problems that make civil defense today quite

different from the civil defense practiced during World War II (FEMA, 1987).

"When a nuclear weapon explodes near the ground it makes a big crater. Earth from the crater is instantly changed from solids into hot gas and fine dust by the tremendous heat of the explosion. This hot gas and dust, together with vaporized materials from the bomb itself, form a giant fireball that rises rapidly high in the air. This becomes the top part of the mushroom cloud of a nuclear explosion (see Figure 1). Dust and the heavier particles of earth make up the stem of the mushroom cloud. The dust and earth in the stem and in the mushroom cloud become radioactive mainly because radioactive materials created in the nuclear explosion stick to some of the dust and earth particles.

**Figure 1.** Graphic depiction of a nuclear explosion and the resultant fallout dispersion (Coyne, 1986).



"As the top of the mushroom spreads out and cools, it forms a cloud of fine particles of earth and debris. This cloud is carried for long distances by the wind and the particles gradually drift down to earth as fallout. The heavier, larger particles settle closer to the point of explosion, but the wind can carry small particles several hundred kilometers (over 150 miles)." (Coyne, 1986).

Once fallout begins to settle, the first 24 hours is the most dangerous period. This initial fallout is highly radioactive The lighter, delayed fallout particles would lose much of their radioactivity in the upper atmosphere (FEMA, 1985a). Delayed fallout reaches the earth in rain or snow over periods ranging from days to years (Michigan Department of State Police, 1985).

The decay of fallout radiation is described by the "seven-ten" rule. This rule states that for every sevenfold increase in time after detonation, there is a tenfold decrease in the radiation rate. For example, if the radiation intensity one hour after detonation is 1,000 Roentgens (measure of radiation exposure) per hour, after seven hours it will have decreased to one-tenth as much. In seven more time periods ( 7 x 7 = 49 hours or two days) the radiation level will be 1/100 of the original rate. After about a two-week period, the level of radiation will be at one-thousandth of the level at one hour after detonation (FEMA, 1985b).

There are three kinds of dangerous radiation in fallout from nuclear weapons: alpha, beta and gamma. All three types of

radiation are dangerous, but gamma radiation poses the greatest threat to human life. Alpha radiation is stopped by the outer skin layers and does not usually present an external hazard (FEMA, 1985b). However, if contaminated air, food or water enters the body in sufficient quantity, by ingestion, inhalation or through skin abrasions, considerable internal damage can occur (Glasstone, 1964). Beta radiation is more penetrating and may cause burns where fallout particles have been deposited on the skin. Gamma radiation is capable of penetrating the entire body and causing damage to organs, blood, and bones (FEMA 1985b). Large doses of gamma radiation can cause sickness or death, depending on the amount of the dose received and victim susceptibility. Small doses incurred over a long period of time may have no immediate effect, but could cause various forms of illness later in life; genetic damage in subsequent generations may also result (FEMA, 1987a).

The above listed effects of a nuclear attack have varying consequences for the populations affected. Those people located near the explosion would be killed or seriously injured by the blast, heat, or initial nuclear radiation. People a few miles away would be subject to blast, heat and fires. A high percentage of the population residing in the lighter damage areas would probably survive these hazards, but might subsequently be endangered by radioactive fallout (FEMA, 1985a).

Another potential effect of nuclear war which has been the subject of popular debate is "nuclear winter". "Nuclear winter" is the term customarily associated with the theory that there will be severe climatic

consequences of nuclear war (Crutzen, 1985). Those who support the nuclear winter theory suggest that a nuclear war could ignite so many fires that dark clouds of smoke spreading over large areas could alter the climate and thus damage ecosystems and agriculture (Center on the Consequences of Nuclear War, 1986). Biologists and ecologists have stated that an average temperature drop of even a few degrees and short-term "quick freezes" could eliminate one or more crop growing seasons and injure or kill tropical species (Scherr, 1985). Highly disturbed ecosystems would offer little support to nuclear war survivors. Survivors would be forced to rely on stored food. Few counties have sufficient food stores to support their populations for a year, and many have only enough food to last a few weeks (Tangley, 1985). Scientific studies have indicated that a nuclear winter might be caused by even very limited nuclear exchanges.

Those who oppose the nuclear winter theory believe that the potential climatic effects might be labeled "nuclear cooling" at best. They predict only days or weeks of temperature drops of 10°C or less; northern hemisphere agriculture would not be wiped out. These theorists suggest the following possible ecological consequences:

1. temporarily increased rainfall,
2. fire hazard in dead forests,
3. longer term threat of increased erosion and silting, and
4. increase in populations of insects and rodents that may carry diseases.

Those who support the nuclear cooling theory have concluded that the earth's climate is exceptionally stable despite severe temporary imbalances (FEMA, 1987a).

"The nuclear winter hypothesis, as is the case with all predictions about the conduct or consequences of nuclear conflicts, can never be fully tested by anything short of a nuclear war itself" (Scherr, 1985).

## HISTORICAL OCCURRENCE AND RESPONSE

Obviously, Montana has no history of nuclear attack. The only experience the United States has had in dealing with the effects of nuclear detonation comes from the bombs dropped on Hiroshima and Nagasaki, Japan, weapon tests performed between 1945 and 1963 in the South Pacific, and at test ranges in the southwestern United States.

Atmospheric tests conducted at the times of these detonations revealed that radioactive fallout could be carried great distances in the atmosphere. The potential seriousness of human exposure to fallout became apparent when studying the medical effects observed in some Marshallese Islanders and Japanese fishermen after the 1954 Bravo test. The controversies surrounding fallout effects on livestock and humans in southern Utah and Nevada further confirmed the dangers. Thyroid dysfunction was the primary effect observed in the Marshallese; children were the most susceptible.

The natural ecosystem surrounding detonation points was also adversely affected. At both the South Pacific and Nevada test ranges, perennial plants (those which have a life cycle of more than two years) recovered more quickly from blast and thermal effects than species that rely on seeds for reestablishment. Seed availability limited reestablishment of some species on the South Pacific test islands. Abnormal plant growth was observed in fresh vegetative growth at both the Nevada and South Pacific test ranges. At the Nevada test range lizards and small mammals exposed to long-term radiation suffered adverse effects to their individual lifespans, time of

sexual maturity, population age distributions and other life-history characteristics (Grover and Harwell, 1985).

Although this historical perspective is enlightening, it does not represent what could occur if a nuclear attack were launched today. Most nuclear war scenarios assume that 5,000 - 6,000 Megatons (Mt) of explosive power would be detonated in a nuclear war over the Northern Hemisphere. Such a war would release in explosive yield $10^9$ to $10^{10}$ tons of TNT equivalent. Expressed another way, a 5,000 Mt war in which one Hiroshima sized bomb was dropped, every second would last four and a half days (Grover and White, 1985).

PREDICTION POTENTIAL FOR RECURRENCE

Obviously the title of this subsection is not entirely appropriate since a hostile attack has never occurred in Montana. This discussion will concentrate on the potential to predict such attacks in the future. The potential for a nuclear attack will exist so long as stockpiles of nuclear weapons exist. The number of nations with sufficient technological development to produce such weapons continues to grow.

Predicting the time and extent of an attack is nearly impossible. The Federal Emergency Management Agency assumes that a surprise attack is very unlikely; a period of heightened international crisis will precede any conflict. The Soviets also believe that war "... is more likely to begin with a crisis period in which both sides would ready their forces and take measures to protect their economics and population" (FEMA, 1987b). In addition, most Soviet authorities expect a conventional war phase to precede a nuclear war (FEMA, 1987b).

The extent of an attack would depend largely on Soviet target selection. According to the Nuclear Attack Planning Base - 1990, potential target considerations include Intercontinental Ballistic Missile (ICBM) silos and launch control centers, other military facilities and complexes, key military support industries, political infrastructure, ports and port facilities, petroleum refineries, electric power generating facilities, and chemical industry facilities. Population is not specified as a Soviet target (FEMA, 1987b).

## STATE VULNERABILITY TO HOSTILE ATTACK

Since Montana has never received a hostile attack of the type being addressed in this section, it is difficult to fully assess future vulnerability. Information in this subsection will, by necessity, be based on predictions made by individuals who monitor the attack environment.

Montana's vulnerability to nuclear attack must be addressed on three levels:

- Vulnerability to direct effects from blast overpressure,
- Vulnerability to the fire risk created by the combined effects of blast overpressure damage and the thermal pulse of a weapon, and
- Vulnerability to the fallout risk from radiation generated by surface-burst weapons.

Figure 2 shows Montana's vulnerability to the direct effects of blast overpressure. This map, published in FEMA's Nuclear Attack Planning Base-1990, is based on information gained from in-house professional expertise, outside specialists, and publicly available Soviet strategic and tactical nuclear warfare doctrines.

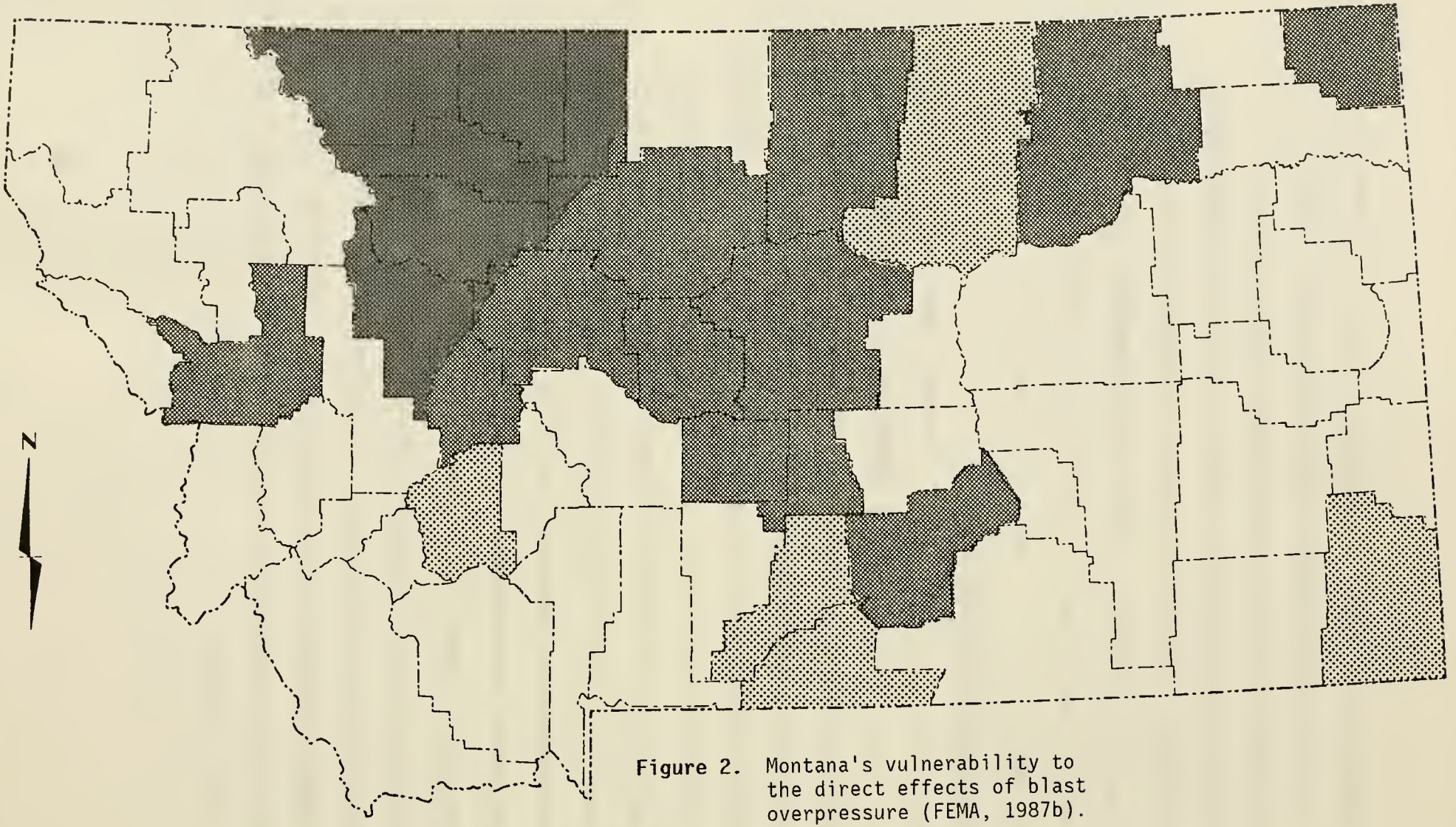



**Figure 2.** Montana's vulnerability to the direct effects of blast overpressure (FEMA, 1987b).

Direct effects are measured in pounds per square inch (psi) of blast overpressure as follows:

Very high = more than 10 psi
High = 5 - 10 psi
Medium = 2 - 5 psi
Low = 0.5 - 2 psi

(Above 2 psi serious blast damage to residential structures can occur.) (FEMA, 1987b)

As can be seen, portions of 17 counties in Montana may be subject to "very high" direct effects of blast overpressure while five counties are considered to be in "medium" direct effects risk areas. No areas were identified as high direct effects risk areas.

Since the fire risk is directly related to the direct effects of blast, this same map indicates areas of vulnerability to fire. Three degrees of fire risk have been delineated according to the strength of the blast:

Very high = above 5 psi
High = 2 - 5 psi
Medium = 0.5 - 2 psi (FEMA, 1987b)

Areas that would either have a "very high" or "high" vulnerability to the direct effects of blast would also have a "very high" vulnerability to fire. Those areas with "medium" vulnerability to blast effects would have a "high" degree of vulnerability to the fire risk (FEMA, 1987b).

In order to determine potential fallout distribution patterns a model was developed. The model uses wind speeds and directions for various altitudes up to the height of a weapon's mushroom cloud. The "most probable" wind patterns for each month of the year were developed by the U.S. Air Force Environmental Technical Applications Center from an analysis of the period January 1977 through September 1981. Also incorporated into the model were the results of a Defense Nuclear Agency study completed in

1986. This study simulated fallout distribution using 40 randomly selected wind patterns from weather data over a five year period. Using both of these studies, predictions of the highest potential fallout radiation dose received by each county unit in the U.S. were determined (FEMA, 1987b). Figure 3 shows the results of these predictions for Montana.

Radiation is usually measured in units called roentgens (R). The risk to human health and life is the amount of such energy absorbed by the body over time, otherwise known as the "total dose." The total dose accumulated during a one week period provides a standard of measurement for assessing the degree of risk from fallout. Table 1 shows exposure criteria for determining the probable risk to human life and health from gamma radiation exposure (FEMA, 1987a).

TABLE 1

OUTCOMES OF EXPOSURE TO GAMMA RADIATION

| Persons Needing Medical Care | Accumulated R Dose Within: One Week | One Month | Four Months |
|---|---|---|---|
| None | 150 | 200 | 300 |
| SOME (5% may die) | 250 | 350 | 500 |
| MOST (50% may die) | 450 | 600 | --- |

Obviously, the fallout radiation dose expected in any part of Montana far exceeds survivable levels.

## MITIGATION

There are two opinions concerning the survivability of nuclear war. Some believe that the entire population will be killed either by the initial blast or by illness brought on by the effects of radiation exposure, regardless of mitigation measures taken.

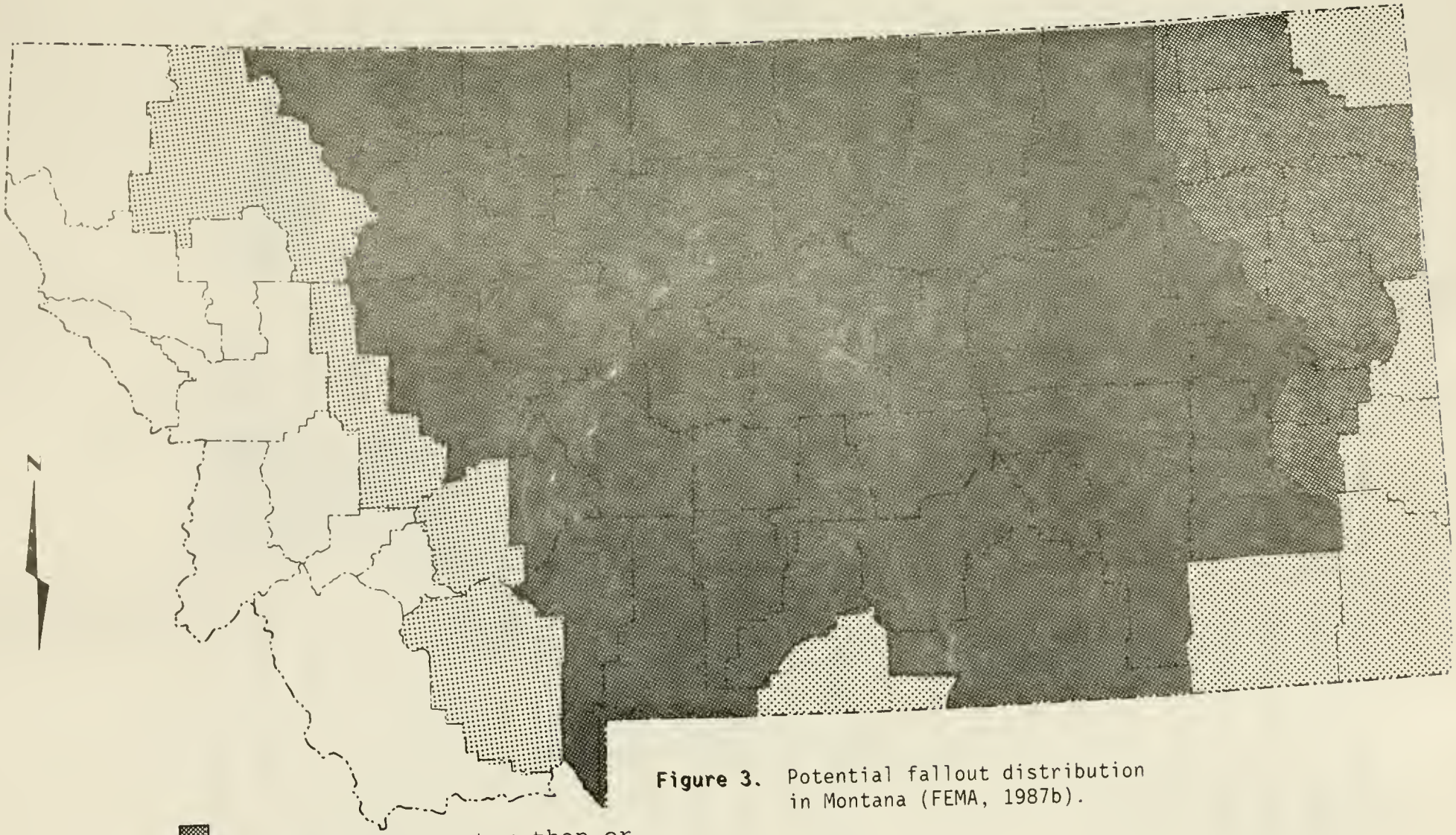



**Figure 3.** Potential fallout distribution in Montana (FEMA, 1987b).

The second opinion is that some portion of the population will survive to rebuild that which has been destroyed. If a nuclear attack is survivable, the mitigation measures suggested below may increase the percentage of survivors.

The major objectives to consider in determining the most effective mitigation measures are:

1. To remove citizens from potential target areas (large industrial cities, communication centers, and air force bases, etc.);
2. To protect people against the hazards of nuclear fallout; and
3. To stockpile food, fuel, medicines and other essential goods for use during and after a nuclear conflict (Greene, 1986).

**Objective #1 - Remove citizens from potential target areas.**

Should there be enough warning before an attack, populations located in potential target areas may be evacuated. Local authorities are responsible for evacuation planning because they are familiar with local factors that might affect such action (FEMA, 1985b). Figure 4, indicates potential fallout conditions in neighboring states in the event that the optimum evacuation plan would be to cross the state boundary.

In order for evacuation plans to be effective, the public must be fully aware of the procedures to be followed. Public information must be given a high priority in civil defense planning. Communication before, during and especially in the wake of a disaster is perhaps the single most important element in mitigating the effects of the disaster. Educating the public must be done in peacetime through the use of a carefully planned information program. Survival instructions should include information on the

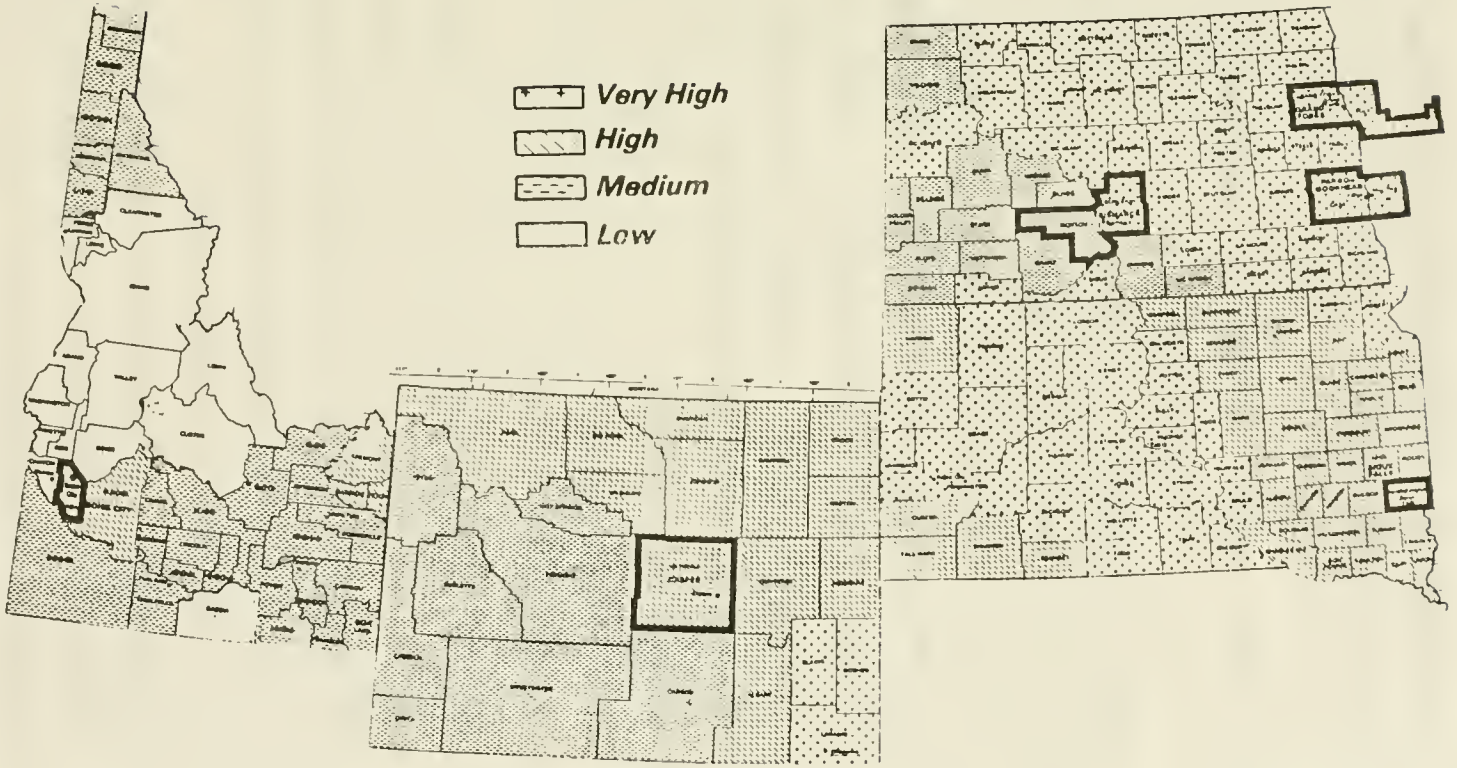



**Figure 4.** Potential fallout conditions in neighboring states (FEMA, 1987b).

following: nuclear weapons; shelter and evacuation; survival rations; fire fighting; first aid; and basic hygiene hints (NATO, 1986).

**Objective #2 - Protect people against hazards of nuclear fallout.**

Those removed from target areas may still be subject to the hazards of fallout.

There are three major factors involved in choosing protection from fallout:

1. The greater the distance between a person and the fallout particles, the less radiation they will receive.
2. Heavy, dense materials provide protection from fallout particles. Concrete, bricks, and earth will absorb many of the gamma rays.
3 Fallout radiation decays fairly rapidly. In most cases, the radiation level would decrease enough to permit people to leave shelter within a few days for short periods of time. Full-time shelter occupancy would probably not be necessary for more than a week or two. Unusual weather conditions or an extended period of attack could prolong the shelter stay (FEMA, 1985a).

A fallout shelter is defined as "any space, provided the walls and roof are thick and dense enough to absorb the rays given off by the fallout particles outside (FEMA 1985a). Some examples of potential fallout shelters include caves, mines, tunnels, underground parking garages, shopping malls, basements, and privately built shelters (Chester, 1987).

Every type of shelter has a different protection factor (PF). The protection factor of a shelter is an expression of the effectiveness of the shielding provided by the structure to reduce gamma radiation (e.g., in a PF 100 shelter, the dose rate of gamma radiation would be .01 of the outside

dose rate) (FEMA, 1987b). Spaces designated as fallout shelters usually have a PF of at least 40. Residential basements in single-family houses provide protection factors of 10-20. By improvising additional shielding around a small corner space, significant protection can be obtained. Spaces with protection factors of 200 - 1,000 would prevent injury or illness from fallout almost anywhere in the country (Chester, 1987).

Due to the variability in expected fallout levels in different parts of Montana, shelter protection factors required for survival also vary. In those parts of the state designated as "high" or "very high fallout risk areas" (see Figure 3), a protection factor of 80 - 100 would yield a probable survival rate of 95 percent. This same survival rate could probably be attained in the "medium fallout risk areas" in shelters with a PF of 30 or above (FEMA, 1987b).

Protective measures against direct effects of weapons have been researched and determined to be possible, but generally impractical due to the enormous expenditures required in the construction of a comprehensive blast shelter system (FEMA, 1987a). Blast protection requires a shelter strong enough to resist blast pressure, initial radiation, heat, and fire as well as radioactive fallout (FEMA, 1985b).

**Objective #3 - Stockpile food, fuel, medicines and other essential goods.**

Even if adequate shelter can be found, it is useless if not stocked to sustain the number of people it will accommodate. At a minimum, shelters must contain drinking water, food, fuel, medicines, and other essential goods for use during and after a nuclear conflict (Greene, 1986).

Planning is the single most important mitigation technique to employ. Without plans that include public information programs, people will move

haphazardly from one target area to another or from a low risk area to a target area. With factual information they will be able to make decisions to secure their own safety and welfare. Plans developed now would assure any crisis operation of progressing more smoothly, more safely. and with greater efficiency than if the situation occurred without prior planning (Sincere, Jr. 1986).

# TERRORIST ATTACK

## DESCRIPTION

Terrorism is defined as the calculated use of violence or threat of violence to attain political or social goals through instilling fear, coercion or intimidation. It involves a criminal act, often symbolic in nature, that is intended to influence an audience beyond the immediate victim.

The primary objectives of most terrorist groups are:

1. to gain publicity,
2. to stimulate loss of confidence in the government,
3. to attract recruits,
4. to get public support,
5. to gain support from financial institutions, and ultimately,
6. to weaken and overthrow the government (U.S. Secret Service, 1987).

Techniques used to gain an audience for their platform include: hostage-taking, product-tampering, criminal extortion, arson, sabotage, threats against individual family members, assassinations, kidnaping, explosive bombings, and armed attacks (Driscoll, 1986).

The most likely targets of these forms of terrorism are political leaders, key military personnel, foreign missions, military facilities, corporate executives and facilities, and celebrities (U.S. Secret Service, 1987).

There are currently nineteen (19) active terrorist groups in thirty (30) states (U.S. Secret Service, 1987). In Montana, the group of primary concern is the Aryan Nations, whose central headquarters is located at Hayden Lake, Idaho, six miles outside of Coeur d'Alene. The stated goal of

this central group, and a dozen splinter organizations, is to create a solely white christian North America. Land that followers currently consider to be part of the Aryan Nation includes 10 million acres in the Provinces of British Columbia and Alberta, Eastern Washington, Western Montana, almost all of Idaho, the northern tip of Utah and part of Wyoming. Devoted followers are considered violent and the groups are becoming stronger every year (Rykman, 1985).

## HISTORICAL OCCURRENCE AND RESPONSE

There have been no confirmed incidents of terrorism in Montana; however, some weapons and vehicles, used to commit acts of terrorism elsewhere, originated in this state (Driscoll, 1987). Since Aryan Nation members claim Western Montana as part of their kingdom, a brief history of this group warrants discussion.

Hayden Lake, Idaho is the home of the Church of Jesus Christ Christian, otherwise known as Christian Identity, otherwise known as Aryan Nations. The Aryan Nations Church has held a World Congress in Hayden Lake nearly every summer since 1979. Founders of this organization chose the northwest because there are few Jews or blacks living here. They believe the races should be kept apart. Aryans consider the blacks to be an inferior race and the Jews to be the children of Satan. Most Aryan groups would like to secede from the Union and form their own nation in the Pacific Northwest.

Two plans have been formulated by Aryans for gaining power over their alleged kingdom. The official plan is to breed so many Aryans that the kingdom will become theirs by default. Impatient followers chose a second plan -- revolt. In 1983 a military branch of the Aryan Nation called The Order, was formed. The Order was modeled after a fictional band of Aryan

warriors in a novel by a neo-Nazi author. The fictional warriors destroy all non-Aryans.

In real life, The Order was comprised of two dozen white men who robbed armored cars to finance their revolution. Among their crimes was the blowing up of a building and the murder of a Jewish radio personality in Denver. By early 1985, the FBI had either killed or imprisoned most of the Order members (Jordan, 1986).

Despite suppression of the Order, the Aryan Nation claims to have acquired 10,000 plus followers, some of whom reside in Montana (Rykman, 1985).

## PREDICTION POTENTIAL FOR RECURRENCE

Terrorism within the United States will probably continue at its current level, which is relatively low (Minetree, III, 1986). Indications that there is a potential for terrorist activity in specific localities include:

- Dissent for political, social, or ethnic reasons; charges brought against local government.
- Formulation of radical groups, branches of national subversive groups, or secret societies.
- Anti-government, anti-U.S. agitation (Driscoll, 1986).

Although membership in the Aryan Nations is growing, the likelihood of this group instigating a terrorist incident of disastrous proportions in Montana is minimal. It is however, necessary to assume that the possibility of terrorism imported from the Middle East, Central America, and the Caribbean Basin is increasing. Bigotry, primarily directed against Jews and blacks, suggests the potential for future terrorism, especially in western

countries where minorities are prevalent. According to J. Lawrence Minetree, III, fear and anger produced in the undeveloped world against the "international capitalist system" will also account for an increased level of violence in the future (Minetree, III, 1986). Again, it is unlikely that Montana would be a target for a terrorist attack involving mass destruction.

The most dangerous variant of terrorism, nuclear violence, could affect Montana. The probability of nuclear terrorism remains low. At present, the most likely form of nuclear terrorism may be threat or hoax involving a nuclear device or sabotage. This method of terrorism could have enormous coercive and disruptive results without mass killing or destruction. Terrorists could pose a nuclear threat in several ways:

- Stealing a bomb;
- Stealing suitable nuclear material and building a bomb;
- Sabotaging and holding for ransom a reactor or other nuclear facility or a shipment of reactor fuel or waste;
- Credibly claiming to have acquired a weapon or the nuclear material to build a bomb or a dispersal device;
- Causing or threatening to cause a serious nuclear accident (Leventhal, 1987).

## STATE VULNERABILITY TO TERRORIST ATTACK

It is impossible to assess Montana's vulnerability to international terrorism. At the present time, the only terrorism to which Montana might be considered vulnerable would be that committed by white supremist groups. It is unlikely that any terrorist act perpetrated by these groups would be of disastrous proportions statewide.

## MITIGATION

Authorities on terrorism generally agree that terrorism cannot be wiped out entirely; for the present, they see it as a problem to be managed, not solved.

Efforts to manage potential terrorism in Montana should include:

- Gathering intelligence on terrorist operations, possible members, and their ideology
- Pooling intelligence and information with other knowledgeable sources (Minetree, III, 1986)
- Physically protecting suspected targets
- Promoting public awareness
- Controlling arms and explosives
- Careful screening of applicants for jobs that require the use of arms and explosives (e.g., law enforcement, military, etc.) (Driscoll, 1987)
- Encouraging the media to engage in self-regulation since, as British Prime Minister Margaret Thatcher has said, publicity is the oxygen of terrorism
- Preparing contingency plans for different kinds of terrorist acts (Kidder, 1987)

## SUMMARY

Hostile attack is the most threatening man-caused hazard that could potentially affect Montana. The types of hostile attack addressed on the preceding pages are nuclear and terrorist.

Montana has no history of either of the types of hostile attack discussed and is unlikely to become a victim, however, the potential exists.

The Federal Emergency Management Agency assumes that a surprise nuclear attack is very unlikely; they believe that a period of heightened international tension will precede any conflict.

Terrorist attacks in other parts of the world have seldom been preceded by any warning. It is unlikely that a terrorist attack in Montana would be preceded by any warning either. However, the probability of a terrorist attack of disastrous proportions affecting Montana is remote.

The mitigation measures suggested for each type of hostile attack obviously differ, however, two measures that apply to both are planning and public information. Plans developed now would ensure more effective coordination of response during any crisis operation, thus providing for safer and more efficient solutions than if the situation occurred without prior planning.

Public information must be given a high priority in civil defense planning. Communication before, during and especially following an attack is perhaps the single most important element in mitigating the effects of these hazards.

## REFERENCES


Becton, J.W., Jr., 1987, FEMA explains NAPB-90: National Coordinating Council of Emergency Management Bulletin, Vol. 4, No. 6, pp. 1-2.

Brown, H., 1983, Thinking about national security - defense and foreign policy in a dangerous world: Westview Press, Boulder, CO., pp. 194-196.

Center on the Consequences of Nuclear War, 1986, Nuclear Winter: 1986 Research update: Hazard Monthly.

Chester, C.V., 1987, Shelter overview 1987: Journal of Civil Defense, August 1987, pp. 18-22.

Clarke, P.C., 1987, American the Vulnerable: American Legion Magazine, May 1987, p. 24.

Covey, C., 1985, Climatic effects of nuclear war: Bio Science, American Institute of Biological Sciences, Vol. 35, No. 9, pp. 563-569.

Coyne, L.J., Farrell, K.G., and Jewsbury, F.E., 1986, Home fallout protection: Emergency Planning Canada, pp. 3-7.

Crutzen, P.J., 1985, The global environment after nuclear war: Environment, Vol. 27, No. 8, p. 6.

Driscoll, J., 1986, Informal presentation on terrorism: Training Operations Section, National Guard.

Driscoll, J., 1987, Informal presentation on terrorism for the staff of Senator Max Baucus: Training Operations Section, National Guard.

FEMA, 1985a, In time of emergency: A citizen's handbook, H-14, Washington, D.C., 38 pp.

FEMA, 1985b, Protection in the nuclear age: H-20, Washington, D.C., 38 pp.

FEMA, 1987a, Attack environment manual: Civil Preparedness Guide Series 2-b, FEMA 125, 126, 128, 129, 130, 131, 132, 133.

FEMA, 1987b, Nuclear attack planning base-1990: Final Project Report.

FEMA, 1987, FEMA gives planners updated information estimating nuclear attack effects: Background, Office of Public Affairs, Washington, D.C.

Glasstone, S. (ed.), 1964, The effects of nuclear weapons: prepared by the U.S. Dept. of Defense, publixhed by the U.S. Atomic Energy Commission, 730 pp.

## REFERENCES - Continued


Grover, H.D., and Harwell, M.A., 1985, Biological effects of nuclear war II: Impact on the biosphere: BioScience, American Institute of Biological Sciences, Vol. 35, No. 9, pp. 576-583.

Grover, H.D., and White, G.F., 1985, Toward understanding the effects of nuclear war: BioScience, American Institute of Biological Sciences, Vol. 35, No. 9, pp. 552-556.

Harnly, C.D., 1985, Agent Orange and the Vietnam veteran: An annotated bibliography: Public Administration Series: Bibliography #P 1623, 160 pp.

Harwell, M.A., 1985, Sleep peacefully: BioScience, American Institute of Biological Sciences, Vol. 35, No. 9, pp. 550-551.

Harwell, M.A., and Grover, H.D., 1985, Biological effects of nuclear war I: Impact on humans: BioScience, American Institute of Biological Sciences, Vol. 35, No. 9, pp. 570-575.

James, B., and Guillen, J., 1986, Modelling fallout propagation: A new approach: Emergency Planning Digest, October-December 1986, pp. 17-21.

Jordan, P., 1986, A fantasyland of white supremacy: Life, Vol. 9, pp. 22-28.

Kahler, K., 1986, War on domestic terror: The Independent Record, Helena, MT, May 3, 1986.

Kidder, R.M., 1987, Readings on Terrorism: U.S. Army Command and General Staff College, Fort Leavenworth, Kansas, Reprinted by permission from The Christian Science Monitor.

Leventhal, P., 1987, Report on nuclear terrorism: Emergency Preparedness Digest, Canada, January-March 1987, pp. 25-29.

Michigan Department of State Police, 1985, Michigan hazard analysis: Emergency Management Division, Lansing, MI, 58 pp.

Minetree, III, J.L., 1986, Terrorism and its impact on search and rescue: Response!, Vol. 5, No. 5, pp. 30-32.

Montana Civil Defense Division, 1976, Hazard/Vulnerability Analysis: Montana Disaster Preparedness Program, pp. 58-62.

Natural Hazards Research and Applications Information Center, 1986, The ultimate environmental threat: Natural Hazards Observer, Vol. X, No. 3, p. 14.

## REFERENCES - Continued

North Atlantic Treaty Organization (NATO), 1986, Compendium of technical information for the basic protection of populations: Senior Civil Emergency Planning Committee and Civil Defense Committee, NATO, HQ, Brussels.

Oster, Sr., R.E., 1987, Fallout radiation: Levels and effects: Journal of Civil Defense, Vol. XX, No. 5, p. 21.

Rykman, L.G., 1985, The Aryan Nation: videotape.

Sagan, C., 1985, Nuclear winter: A report from the world scientific community: Environment, Vol. 27, No. 8, p. 12.

Scherr, S.J., 1985, Coming to grips with nuclear winter: Environment, Vol. 27, No. 8, p. 4.

Sincere, Jr., Richard E., 1986, Civil defense: A moral, political, and strategic approach: Ethics and Public Policy Essay #65, Ethics and Public Policy Center, Washington, D.C., 19 pp.

Tangley, L., 1985, The year after: BioScience, American Institute of Biological Sciences, Vol. 35, No. 9, pp. 536-540.

U.S. Secret Service, Office of Training, 1987, Protective Operations Briefing, Butte, MT, October 27-28, 1987.

Van Strum, C., 1983, A bitter fog - Herbicides and human rights: Sierra Club Books, San Francisco, 288 pp.